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TM 9-5000-15

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

NIKE I SYSTEMS
COMPUTER
STEERING SECTION
CIRCUITRY (U)

DEPARTMENT OF THE ARMY • APRIL 1956

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TM 9-5000-15, Nike I Systems, Computer Steering Section Circuitry (U), is published for the use of all concerned.

The special texts in the TM 9-5000-series are training supplements to those in the TM 9-5001-series which are the basic Army directives for the operation and maintenance of the NIKE I Guided Missile System. In the event of conflict, technical manuals in the basic TM 9-5001-series will govern.

[AG 413.44 (3 Apr 56)]

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NG: None.
USAR: None.
For explanation of abbreviations used, see SR 320-50-1.

CONTENTS

CHAPTER 1

THE COMPUTER STEERING SECTION BLOCK DIAGRAM

Section I. GENERAL DISCUSSION

1. PURPOSE AND SCOPE

a. Purpose. The purpose of this special text is to present to the reader a block diagram discussion and a detailed discussion of the computer steering section.

b. Scope. This discussion presents the general functioning mathematical analysis, and detailed circuit operation of each unit in the steering section of the computer. The block diagram discussion gives the reader an over-all picture of the operation of the section so that, with the detailed discussion that follows, a complete understanding of the operation of the system may be gained.

2. REFERENCES

a. References. References to other special texts will be of the form "TM 9-5000-9" with the appropriate paragraph number. References to a general circuit will be of the form "TM 9-5000-26, page 162" and will refer to the page or first of several pages on which the circuit is shown. References of the form "(108C4)" refer to TM 9-5000-26 by page number and the zone numbering system found on page ii of TM 9-5000-26. This reference system is used to point out specific items within a schematic. References of the form "(16C13)" refer to the sheet number and zone number system also found on page ii of TM 9-5000-26. This reference system has been avoided wherever possible.

b. Definitions. Definitions of the symbols and abbreviations used in this text will be found in TM 9-5000-13, appendix I.

3. GENERAL

The prelaunch section, discussed in TM 9-5000-14, was designed to solve for the predicted intercept point, the gyro azimuth, and the predicted time of flight. The steering section uses this information as its initial solution. When the steering section takes control, the missile should be flying approximately the correct course. The steering section determines the steering orders that

will cause the missile to fly a course to intercept the target. The steering section must determine if the target is maneuvering, and if so, send orders to the missile changing its flight path to counter the maneuvers. If the steering section is to do its job, it must know the present position of the target and the missile as determined by the target- and missile-tracking radars. Also, it must know the distance between the two tracking radars. From the above data, the steering section can determine the velocities of both the target and the missile, the closing velocity, the time to intercept, and the climb and turn angles of the missile. It can then determine the orders to send to the missile to direct it to intercept the target, and the correct time to send the burst order.

Section II. BLOCK DIAGRAM DISCUSSION

4. THE STEERING SECTION (TM 9-5000-26, p 64)

The steering section of the Nike I computer consists of the following units:

a. Radar-to-radar parallax unit.

b. Target coordinate converter.

c. Missile coordinate converter.

d. Closing speed solver.

e. Target steering differentiators.

f. Missile differentiators.

g. Steering error solver.

h. Steering error converter.

i. Time-to-intercept servo.

j. Fin order solver.

k. Burst order circuits.

l. Missile rate converter.

m. Climb angle servo.

n. Turn angle servo.

This section is a discussion of the general function and mathematical operation of each of these units.

5. RADAR-TO-RADAR PARALLAX UNIT

The target-tracking radar is used as the origin or center of the earth coordinate system, and all computations are referred to this point. The radar-to-radar parallax unit serves a similar function during the missile flight phase, as did the launcher parallax unit during the prelaunch phase. The outputs of the radar-to-radar parallax unit are determined by handset potentiometers. The outputs, X_R, Y_R, and H_R, represent the rectangular coordinates of the missile-tracking radar, with respect to the position of the target-tracking radar. These outputs are sent to the closing speed solver.

6. TARGET COORDINATE CONVERTER

The mathematics performed by the target coordinate converter are discussed in **TM 9-5000-14,** paragraph 6. The inputs to the unit are D_T, A_T, and E_T, the present position of the target in spherical coordinates. The target coordinate converter converts the inputs into rectangular coordinates H_T, X_T, and Y_T and sends them to the target-steering differentiators and closing speed solver.

7. MISSILE COORDINATE CONVERTER

The mathematics performed by the missile coordinate converter are discussed in **TM 9-5000-14,** paragraph 9. The inputs to the unit are D_M, A_M, and E_M, the present position of the missile in spherical coordinates, received from the missile-tracking radar. This unit converts these inputs into rectangular coordinates H_M, X_M, and Y_M and sends them to the missile differentiators and closing speed solver.

8. CLOSING SPEED SOLVER

The closing speed solver solves for the ideal closing velocities, $\frac{X}{t}$, $\frac{Y}{t}$, and $\frac{H}{t}$, between the missile and the target. The inputs to this unit are the target position and missile position in rectangular coordinates, radar-to-radar parallax, and the time to intercept. As an example of the solution which takes place in the closing speed solver, assume that the target is flying toward the radars from the east, and that the missile has been launched and is flying toward the target. The radar-to-radar parallax coordinates representing the position of the MTR (missile-tracking radar) with respect to the TTR (target-tracking radar) are added to the coordinates representing the missile position (fig 1).

a. The total distance from the target-tracking radar to the position of the missile is equal to $X_R + X_M$. This value is subtracted from the distance to the target, X_T.

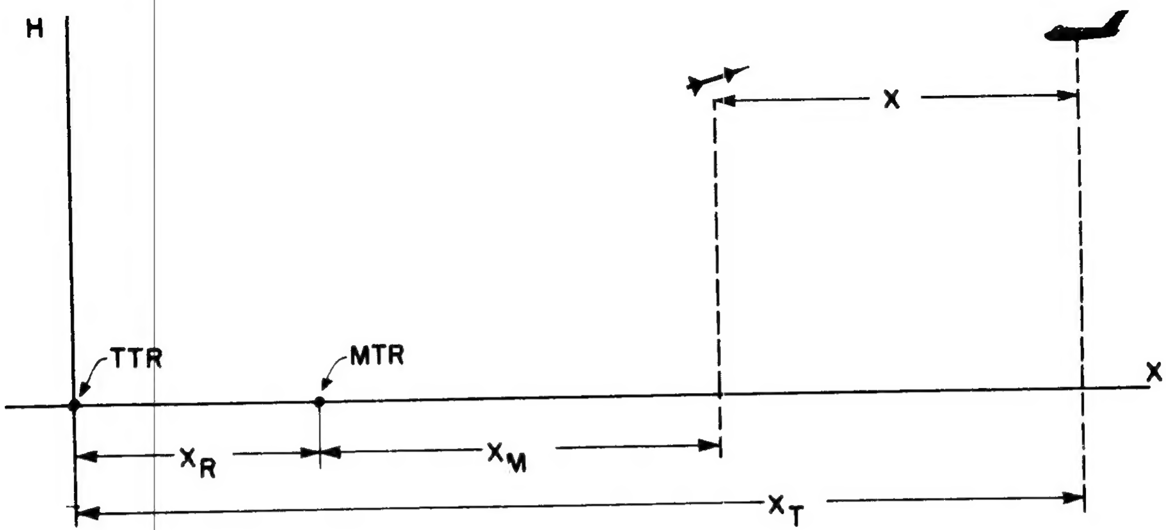


Figure 1. Operation of the closing speed solver in X - H plane.

b. The component of the target position with respect to the missile is found by the formula, $X_T - (X_R + X_M) = X$. If X is divided by the time to intercept, t, the quotient will represent the component of ideal velocity along the X-axis at which the target and missile should be approaching each other.

c. The quantity, $\frac{X}{t}$, is the ideal closing velocity.

$$\frac{X_T - (X_R + X_M)}{t} = \frac{X}{t}. \tag{1}$$

Similarly, in the Y- and H-channels the closing speed solver solves for the velocity components with which the target and missile should approach one another. These ideal closing velocities, $\frac{X}{t}$, $\frac{Y}{t}$, and $\frac{H}{t}$, are sent to the steering error solver.

9. TARGET-STEERING DIFFERENTIATORS

The inputs to this component are X_T, Y_T, and H_T, the rectangular coordinates of the target position. The differentiators determine the time rate of change of position. This rate of change is defined as velocity. Therefore, the outputs of the target-steering differentiators are the X-, Y-, and H-components of target velocity, $\dot{X}_T$, $\dot{Y}_T$, and $\dot{H}_T$, which are sent to the steering error solver.

10. MISSILE DIFFERENTIATOR

The inputs to this unit are the rectangular coordinates of missile position, X_M, Y_M, and H_M. As in the target differentiators, the time rate of change is determined. The outputs of the missile differentiators are the X-, Y-, and H-components of missile velocity, $\dot{X}_M$, $\dot{Y}_M$, and $\dot{H}_M$. These go to the steering error solver; $\dot{X}_M$ and $\dot{Y}_M$ also go to the missile rate converter; and $\dot{H}_M$ goes to the climb angle servo.

11. STEERING ERROR SOLVER

The steering error solver determines whether the missile is flying the correct course to intercept the target. To do this, the solver first subtracts the missile velocity from the target velocity.

$$\dot{X}_T - \dot{X}_M = \dot{X}, \quad (2)$$

$$\dot{Y}_T - \dot{Y}_M = \dot{Y}, \quad (3)$$

$$\dot{H}_T - \dot{H}_M = \dot{H}. \quad (4)$$

The results of this subtraction are the components of the actual closing velocity between the missile and the target. The next step is to compare the components of the actual closing velocity with the components of the ideal closing velocity, as determined by the closing speed solver. If the results of these comparisons are zero, i.e., the actual closing velocity equals the ideal closing velocity, no steering error exists, and the missile is flying the correct course. If the results of the comparisons are not all zero, then a steering error exists. These steering errors are designated S_X, S_Y, and S_H, the steering errors along the X, Y, and H axes, respectively, and are sent to the steering error converter. The formulas the steering error solver uses in the horizontal plane are:

$$S_X = \frac{X}{t} + \dot{X} = \frac{X}{t} + \dot{X}_T - \dot{X}_M, \quad (5)$$

$$S_Y = \frac{Y}{t} + \dot{Y} = \frac{Y}{t} + \dot{Y}_T - \dot{Y}_M. \quad (6)$$

In the vertical plane, an additional velocity is added which will cause the missile to fly toward a point $1/4(gt^2)$ above the target and along a $1/2(g)$ trajectory. This input is $(1/4 + 1/6)gt$. Thus, the formula for S_H becomes:

$$S_H = \frac{H}{t} + \dot{H}_T - \dot{H}_M + (1/4 + 1/6)gt. \quad (7)$$

12. STEERING ERROR CONVERTER

To determine the orders to be sent to the missile, the steering errors must be resolved from earth axes into missile gyro axes, and from gyro axes into missile fin axes. The missile is oriented to the ground guidance equipment only because of the gyro characteristic of maintaining itself in the same plane at all times. The missile itself may be traveling up, down, left, or right of the gyro plane, but at FIRE, the A_G servo freezes the A_G information in the computer and sets the position of the roll amount gyro in the missile to the same A_G. This is the connecting link between the computer and the missile. The inputs to the steering error converter are the components of steering errors in the earth coordinates, S_X, S_Y, and S_H; the gyro azimuth of the predicted intercept point, A_G; the climb angle of the missile, CA; and the turn angle of the missile, TA. The first job the steering error converter performs is to resolve the components of steering errors along the gyro coordinates using sine and cosine values of A_G. In figure 2, the axes have been rotated in the X-Y plane through an angle, A_G. Figure 2 also shows how the values for the steering errors in gyro

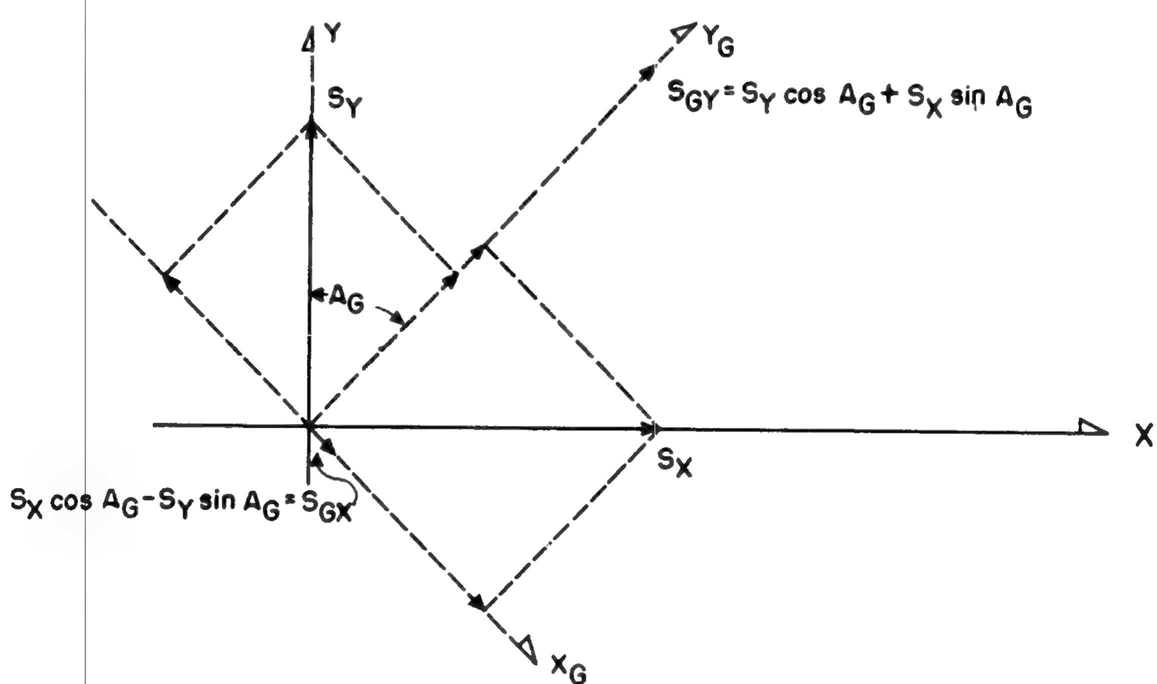


Figure 2. Resolution of steering errors from earth-to-gyro axes.

coordinates, S_{GX} and S_{GY}, are determined. Referring to the figure, the following formulas are derived:

$$S_{GX} = S_X \cos A_G - S_Y \sin A_G, \tag{8}$$

$$S_{GY} = S_Y \cos A_G + S_X \sin A_G. \tag{9}$$

The vertical component of steering error S_H is the same in both earth and gyro axes because the vertical axes of both systems remain parallel. The steering errors are now referred to the missile gyro axes. If climb angle CA and turn angle TA are not both zero, the computer must resolve the components of steering error in gyro coordinates to components of steering error along the missile axes. The first step in this resolution is to resolve the steering error components in the gyro reference plane into components that lie along the climb axes and the L_i line (fig 3). Referring to figure 3, the following formulas are derived:

$$S_C = S_{GH} \cos CA - S_{GY} \sin CA, \tag{10}$$

$$S_i = S_{GH} \sin CA + S_{GY} \cos CA. \tag{11}$$

Note that the quantity, S_i, is the component of steering error that lies along the L_i line. It also lies in the missile velocity slant plane. It is necessary to compute this quantity to determine the components of steering error that lie along

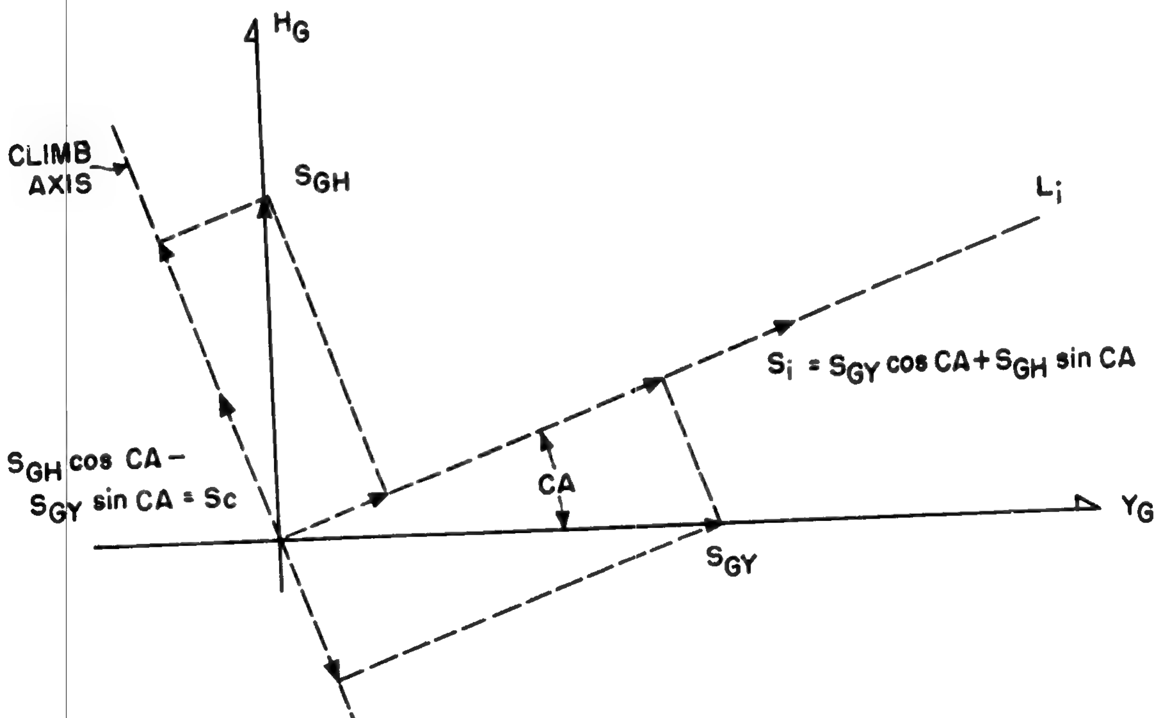


Figure 3. Steering errors resolved along the missile climb axis and the L_i line.

the missile velocity axis and in the missile velocity slant plane. The second step in the resolution is to convert these components of steering error that lie in the missile velocity slant plane, S_i and S_{GX}, into components which lie along the missile velocity axis, S_V, and along the missile turn axis, S_T (fig 4). Referring to figure 4, the following formulas are derived:

$$S_V = S_i \cos TA + S_{GX} \sin TA, \tag{12}$$

$$S_T = S_{GX} \cos TA - S_i \sin TA. \tag{13}$$

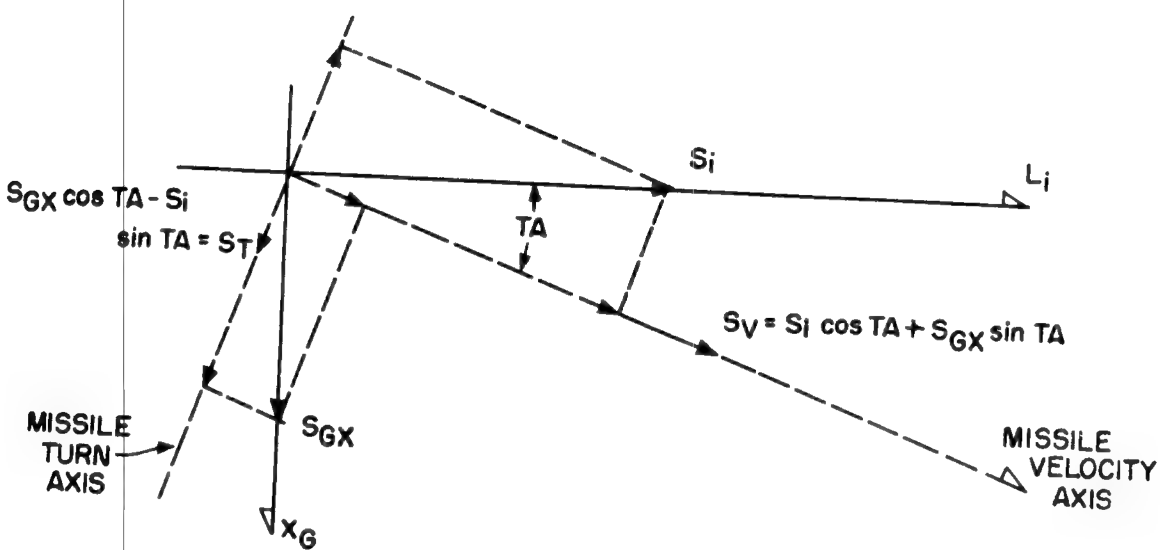


Figure 4. Steering errors resolved along the missile turn and missile velocity axes.

The computer does not solve for the actual value of S_i, but substitutes the equation for S_i in equations (12) and (13). The actual solutions used by the steering error converter are:

$$S_V = S_{GH} \sin CA \cos TA + S_{GY} \cos CA \cos TA + S_{GX} \sin TA, \tag{14}$$

$$S_T = S_{GX} \cos TA - S_{GH} \sin CA \sin TA - S_{GY} \cos CA \sin TA. \tag{15}$$

13. TIME-TO-INTERCEPT SERVO

During the prelaunch configuration, the time-of-flight servo solves for the time of flight of the missile from roll stabilization to the intercept point. At roll stabilization, the time-of-flight servo is changed over to a time-to-intercept

servo and gives a continuous solution for the remaining time to intercept. If the computation for the time of flight is correct and the target does not change its speed or direction, the time to intercept will decrease at a second-per-second rate. A bias voltage applied to the time servo in the computer will cause the time to clock down at a second-per-second rate. If the target starts to maneuver, the intercept point will be changed and the missile must change its course and the remaining time to intercept will change. When the target changes its course, its velocities will change. This will cause a steering error to exist in the steering error solver. These errors are then resolved along the missile axes by the steering error converter. The steering error along the missile velocity axis, S_V, changes the solution for the remaining time to intercept. If the original time solution was too large, then the time must clock down faster than a second-per-second rate. If the original solution was too small, then the time must clock down slower than a second-per-second rate. In the computer, a voltage representing S_V is combined with the second-per-second bias and causes the time servo to clock down at a rate faster or slower than a second-per-second rate, depending upon the polarity of the S_V voltage. The loop that enables the time-to-intercept servo to solve for the remaining time to intercept includes the closing speed solver, the steering error solver, the steering error converter, and the time-to-intercept servo. The output of the time-to-intercept servo is sent as a shaft position to the fin order solver, the closing speed solver, and the burst order circuit.

14. FIN ORDER SOLVER

The inputs to this block are the velocity components of the steering errors along the missile climb axis, S_C; along the missile turn axis, S_T; and the time to intercept, t. Since the guidance fin planes on the missile are set at 45° with respect to the horizontal and vertical planes, the fin order solver must determine the error that lies along the fin axes, and from these errors it determines the correct orders to send to the missile. Figure 5 shows steering errors S_C and S_T resolved into errors along the Y- and P-fins.

$$\text{Error along Y-fin} = S_C \cos 45° - S_T \sin 45° = (S_C - S_T)\,0.707.$$

$$\text{Error along P-fin} = S_C \sin 45° + S_T \cos 45° = (S_C + S_T)\,0.707.$$

These errors are still in terms of velocity. The orders sent to the missile must be in terms of acceleration. The velocity errors must be divided by time to obtain acceleration. The computer obtains the acceleration orders by dividing the errors along the Y-fin and P-fin by the remaining time to intercept. Also, since these errors lie along the Y-fin or P-fin, the correction is applied to the other pair of fins, P-fin and Y-fin, respectively. The formulas for the acceleration orders are:

$$G_P = \frac{(S_C - S_T)\,0.707}{t}, \tag{16}$$

$$G_Y = \frac{(S_C + S_T)\,0.707}{t}. \tag{17}$$

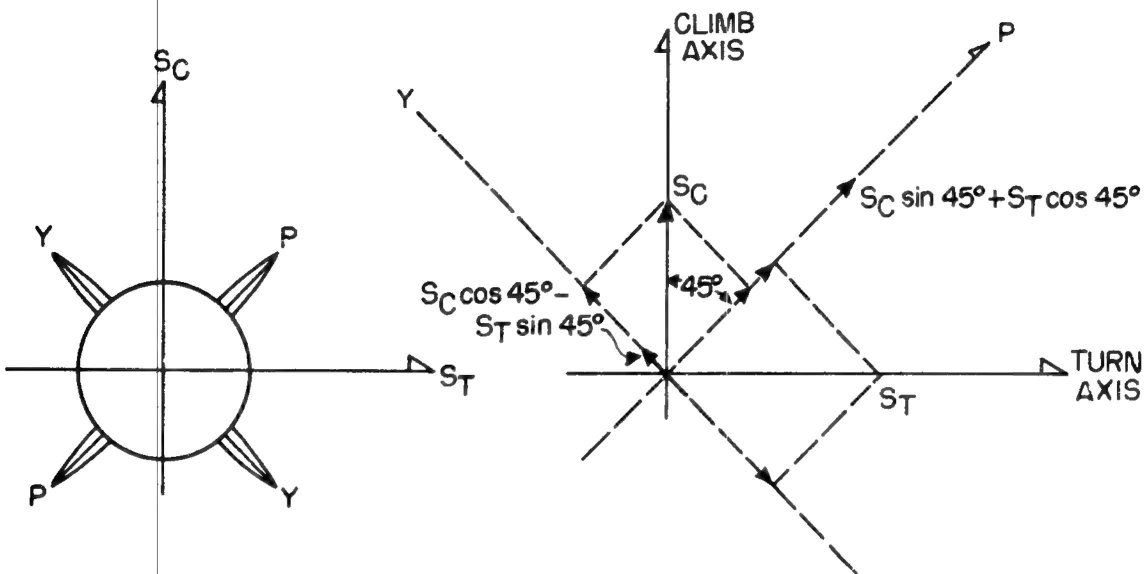


Figure 5. Resolving steering errors along fin planes.

The orders determined above are the accelerations necessary to cancel the steering error in the remaining time to intercept. It is necessary, however, to apply slightly more than the minimum order required to reduce the steering error to zero before intercept occurs. It will be shown in paragraph 54 that these orders are modified to correct the flight of the missile in two-thirds of the remaining time to intercept. Another constant is also added to change the scale factor so that the output of the fin order solver will be in g's of acceleration. These modifications give the formulas:

$$G_P = 0.1975\,\frac{S_C - S_T}{t}, \tag{18}$$

$$G_Y = 0.1975\,\frac{S_C + S_T}{t}. \tag{19}$$

These are the formulas used by the G_Y and G_P amplifiers. The maximum order to each pair of fins is 5g's of acceleration, which gives the resultant maximum acceleration of 7g's in the initial dive order. In a general sense, it should be noted that the steering orders, G_Y and G_P, are not separate and distinct from the steering errors. Actually, it might be said that the steering errors are applied to the missile as orders to cause the missile to change its position until

the errors are zero. When this occurs, there is no error left to be applied to the missile as an order, and the missile is flying the correct course.

15. BURST-ORDER CIRCUIT

The input to the burst-order circuit is an electrical voltage representing the time to intercept. A negative voltage, called the burst-time bias voltage, is also set into the burst-order circuit by a handset potentiometer. This voltage can be set by the battery commander so that the burst order will be sent at any desired time to intercept in the range from t = 0 to t = 200 milliseconds. When the summation of the positive voltage representing time to intercept and the negative burst-time bias voltage equals zero, a relay that allows a burst order to be sent to the missile is energized.

16. MISSILE RATE CONVERTER

The previous discussion has shown basically how the steering section of the computer operates. However, in discussing the steering error and the steering order determining circuits, certain quantities were assumed to be given. These were the climb angle, CA, and turn angle, TA, of the missile. These quantities must also be computed by the computer. These angles are calculated by using the velocity components of the missile. Since the climb angle and turn angle are measured with respect to the gyro reference plane, the velocity components that must be used are components of missile velocity in gyro coordinates. The outputs of the missile differentiators are components of missile velocity in earth coordinates. The missile rate converter converts the components in the earth coordinates into velocity components, which lie in the gyro coordinates. Since the earth and gyro H-axes are parallel, there is no need to convert $\dot{H}_M$. The only components the missile rate converter must convert are $\dot{X}_M$ and $\dot{Y}_M$ to $\dot{X}_{GM}$ and $\dot{Y}_{GM}$. Figure 6 shows the method used by the missile rate converter to determine the value of $\dot{X}_{GM}$ and $\dot{Y}_{GM}$. Referring to figure 6, the following formulas are determined:

$$\dot{Y}_{GM} = \dot{X}_M \sin A_G + \dot{Y}_M \cos A_G, \tag{20}$$

$$\dot{X}_{GM} = \dot{X}_M \cos A_G - \dot{Y}_M \sin A_G. \tag{21}$$

These are the formulas used by the missile rate converter. $\dot{Y}_{GM}$ is sent to the climb angle servo and $\dot{X}_{GM}$ to the turn angle servo.

17. CLIMB ANGLE SERVO

The climb angle is the angle between the missile velocity slant plane and the horizontal plane. The climb angle servo generates a mechanical output in the

form of a shaft position, which represents the climb angle. It also determines the component of missile velocity that lies along the L_i line, V_i. The climb angle servo uses the velocity components, $\dot{H}_M$ and $\dot{Y}_{GM}$, to determine the climb angle and the value of V_i. Figure 7 shows the method used to compute the climb angle. From trigonometry, the following equation may be derived:

$$\tan CA = \frac{\dot{H}_M}{\dot{Y}_{GM}} = \frac{\sin CA}{\cos CA}. \qquad (22)$$

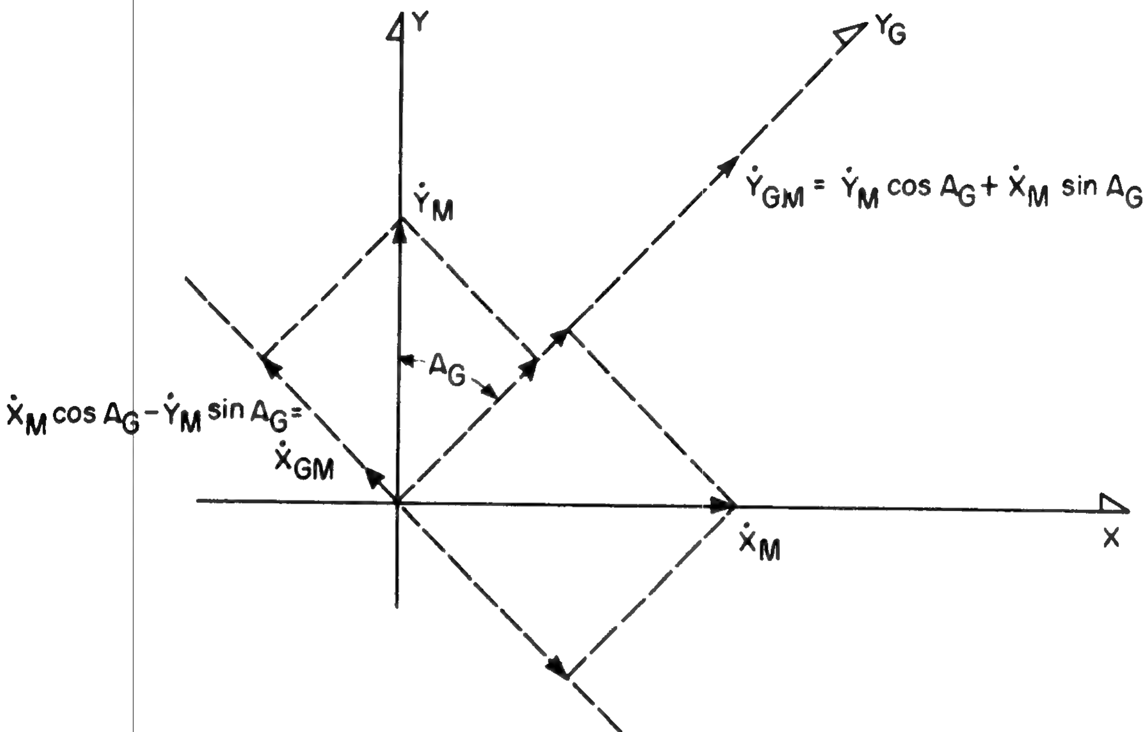


Figure 6. Resolving missile velocity from earth-to-gyro axes.

Rewriting this into a form the computer can use:

$$\dot{Y}_{GM} \sin CA = \dot{H}_M \cos CA, \qquad (23)$$

$$\dot{Y}_{GM} \sin CA - \dot{H}_M \cos CA = 0. \qquad (24)$$

This is the equation the climb angle servo solves. Also, V_i can be calculated by using velocity components $\dot{H}_M$ and $\dot{Y}_{GM}$ (fig 7). The quantities, $\dot{H}_M$ and $\dot{Y}_{GM}$, both have components that lie along the L_i line. The component of $\dot{Y}_{GM}$ is

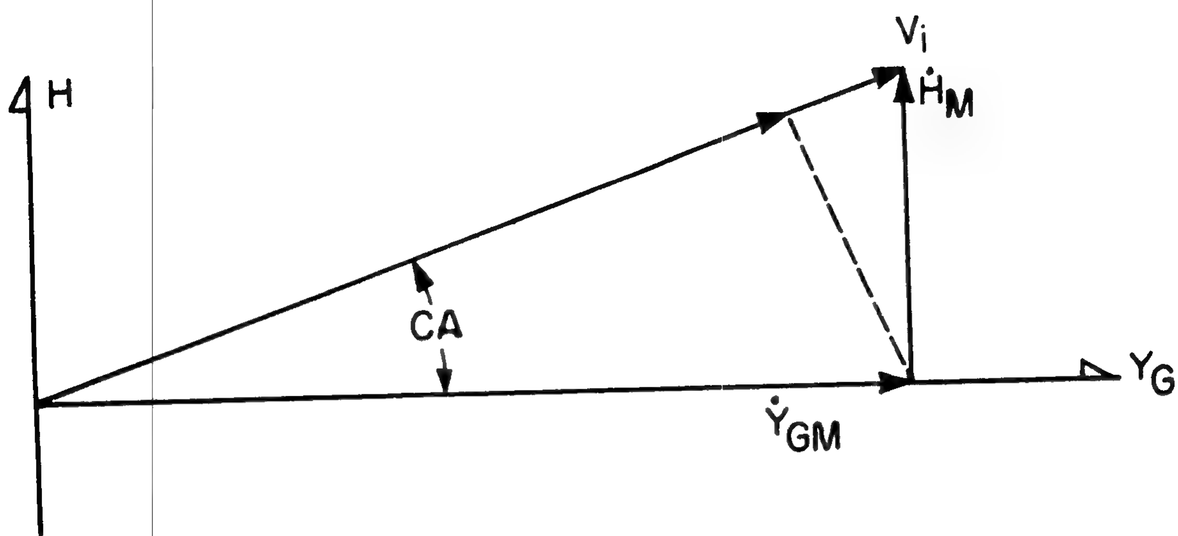


Figure 7. Trigonometric solution of climb angle.

$\dot{Y}_{GM}$ cos CA. The component of $\dot{H}_M$ is $\dot{H}_M$ sin CA. Summing these two components along the L_i line will give the value of V_i.

$$V_i = \dot{Y}_{GM} \cos CA + \dot{H}_M \sin CA. \tag{25}$$

The inputs to the climb angle servo are $\dot{H}_M$ from the differentiators and $\dot{Y}_{GM}$ from the missile rate converter. The output, CA, goes to the steering error converter. The sum, V_i, is sent to the turn angle servo.

18. TURN ANGLE SERVO

The turn angle is the angle between the gyro reference plane and the missile velocity axis, measured in the missile velocity slant plane. The turn angle servo generates a mechanical output in the form of a shaft position, which represents the turn angle of the missile. This angle may be computed by using the component of missile velocity along the L_i line, V_i, and the component of missile velocity along the gyro X-axis, $\dot{X}_{GM}$. From the trigonometric relations between the sides and angles of a right triangle, the turn angle servo computes the turn angle of the missile (fig 8):

$$\tan TA = \frac{\dot{X}_{GM}}{V_i} = \frac{\sin TA}{\cos TA}, \tag{26}$$

$$\dot{X}_{GM} \cos TA - V_i \sin TA = 0. \tag{27}$$

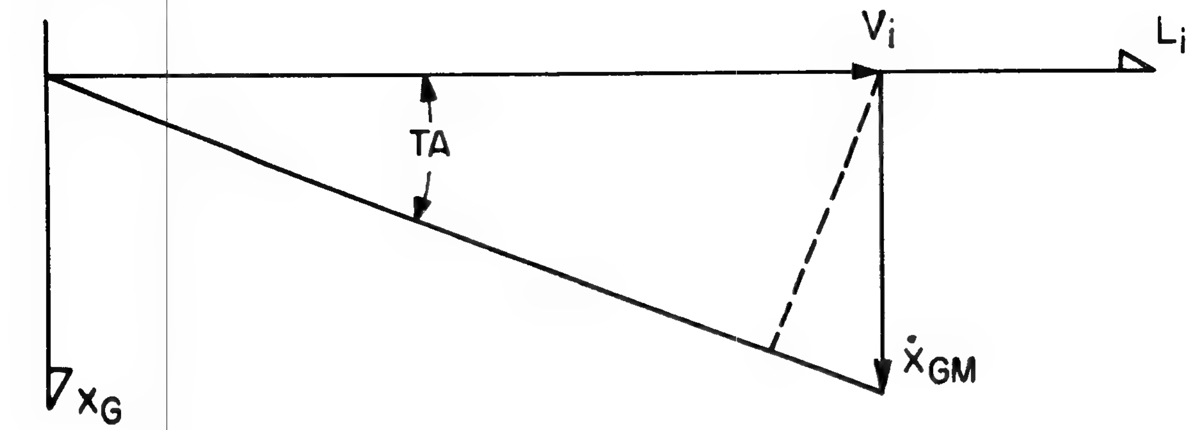


Figure 8. Trigonometric solution of turn angle.

The inputs to the turn angle servo are V_i from the climb angle servo and $\dot{X}_{GM}$ from the missile rate converter. The output, TA, is sent to the steering error converter.

CHAPTER 2

STEERING SECTION DETAILED CIRCUITRY DISCUSSION

Section I. GENERAL DISCUSSION

19. INTRODUCTION

This chapter will provide the reader with a detailed discussion of the units incorporated in the steering section of the Nike I computer. Each unit discussion includes, where applicable, a mathematical analysis of circuit operation, a discussion of the purpose of the unit, a detailed circuit analysis, and a description of the mechanical operation.

Section II. MISSILE RATE CONVERTER

20. GENERAL

The missile rate converter rotates missile velocity components from earth coordinate axes to gyro coordinate axes. Missile velocities are determined originally along the earth coordinate axes. The climb and turn angles, however, are referenced to the gyro coordinate system. To use missile velocities to determine the climb and turn angle solution, the components of missile velocity which lie along the gyro coordinate axes must be determined.

21. MATHEMATICAL ANALYSIS

The components of missile velocity in earth coordinates must be resolved into components of missile velocity in gyro coordinates. In doing this, each component of velocity in earth coordinates is resolved into its components which lie parallel to the Y_G and X_G axes. The components of $\dot{Y}_M$ are: $\dot{Y}_M \cos A_G$ (parallel to the Y_G axis) and $\dot{Y}_M$ $\sin A_G$ (parallel to the X_G axis) (fig 9). The components of $\dot{X}_M$ are: $\dot{X}_M \sin A_G$ (parallel to the Y_G axis) and $\dot{X}_M \cos A_G$ (parallel to the X_G axis) (fig 10). The values of $\dot{X}_{GM}$ and $\dot{Y}_{GM}$ are determined by summing all vectors which lie parallel to the X_G and Y_G axes. In doing this (fig 11), the following formulas are derived:

$$\dot{Y}_{GM} = \dot{Y}_M \cos A_G + \dot{X}_M \sin A_G, \tag{28}$$

$$\dot{X}_{GM} = \dot{X}_M \cos A_G - \dot{Y}_M \sin A_G. \tag{29}$$

22. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, p 66)

The missile rate converter solves the equations for $\dot{X}_{GM}$ and $\dot{Y}_{GM}$. Both positive and negative voltages representing missile velocity in the earth coordinates, $\dot{X}_M$ and $\dot{Y}_M$, are applied to the sin-cos A_G potentiometer cards. The

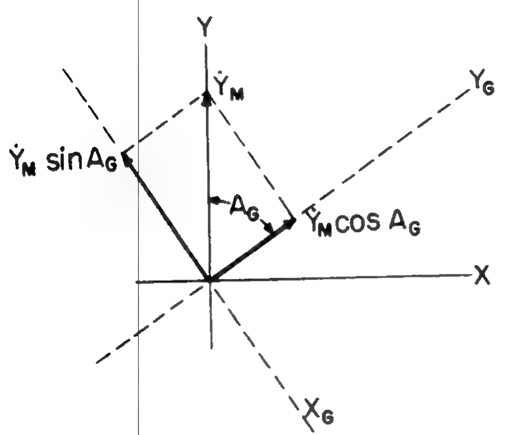


Figure 9. Resolution of $\dot{Y}_M$.

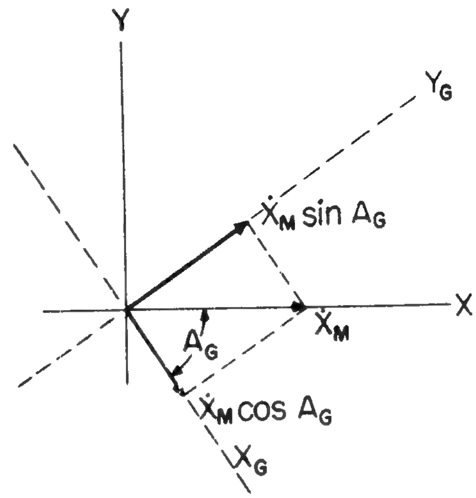


Figure 10. Resolution of $\dot{X}_M$.

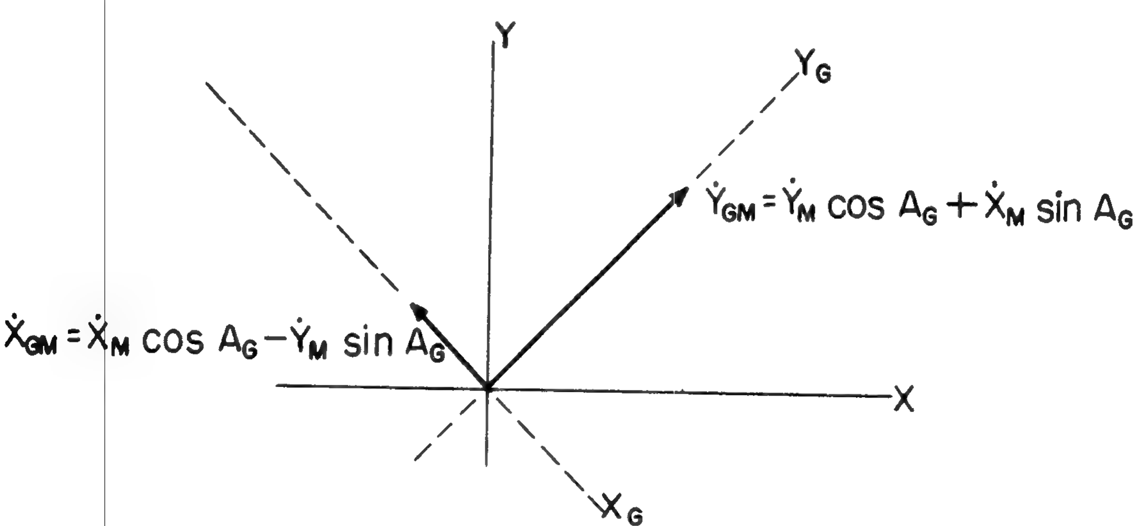


Figure 11. Result of summing of components of $\dot{X}_M$ and $\dot{Y}_M$.

outputs taken from the brush arms are the components of missile velocity in gyro coordinates. These outputs are applied to the $+\dot{X}_{GM}$ and $+\dot{Y}_{GM}$

amplifiers, where they are summed in the input networks. The input to the $+\dot{X}_{GM}$ amplifier is:

$$-\dot{X}_{GM} = -\dot{X}_M \cos A_G + \dot{Y}_M \sin A_G, \tag{30}$$

and the input to the $+\dot{Y}_{GM}$ amplifier is:

$$-\dot{Y}_{GM} = -\dot{X}_M \sin A_G - \dot{Y}_M \cos A_G. \tag{31}$$

The plus or minus sign in the input network or amplifier block indicates the polarity of the output voltage of the amplifier for positive quantities. The output of the $+\dot{X}_{GM}$ amplifier is $+\dot{X}_{GM}$; the output of the $+\dot{Y}_{GM}$ amplifier is $+\dot{Y}_{GM}$. This means that if $\dot{X}_{GM}$ is a positive quantity, it will be represented by a positive d-c voltage at the output of the $+\dot{X}_{GM}$ amplifier. The d-c amplifiers have a gain of one and reverse the polarity of the input. The quantities $+\dot{X}_{GM}$ and $+\dot{Y}_{GM}$ are applied as inputs to the $-\dot{X}_{GM}$ and $-\dot{Y}_{GM}$ amplifiers, which also have a gain of one and reverse the polarities of their inputs. Thus, the output of the $-\dot{X}_{GM}$ amplifier is $-\dot{X}_{GM}$, and the output of the $-\dot{Y}_{GM}$ amplifier is $-\dot{Y}_{GM}$. Notice that the positive amplifier input networks use 1-megohm resistors rather than the normal 0.5-megohm resistors used in d-c amplifiers. These larger input resistors prevent loading of the potentiometers; that is, the outputs are kept linear over the entire range. The outputs of the missile rate converter are sent to the CA and TA potentiometers on the climb and turn servo in the computer servo cabinet.

Section III. CLIMB ANGLE SERVO

23. GENERAL

The climb angle servo determines the missile climb angle. Steering errors are determined in the earth coordinate system. These errors must be made available in a coordinate system which is related to the missile. To do this, these steering errors must be rotated through the climb and turn angles. For this reason, the missile climb angle must be determined.

24. MATHEMATICAL ANALYSIS

The mathematics performed by the CA servo requires the use of $\dot{H}_M$ from the missile differentiator and $\dot{Y}_{GM}$ from the missile rate converter. The servo is constructed so that it must compare two values to arrive at a solution. The formula used by the CA servo may be derived by a trigonometric solution. In figure 12, the climb angle may be calculated by the relation:

$$\tan CA = \frac{\dot{H}_M}{\dot{Y}_{GM}} = \frac{\dot{H}_{GM}}{\dot{Y}_{GM}}, \tag{32}$$

and since

$$\tan CA = \frac{\sin CA}{\cos CA},$$

this equation may be written thus:

$$\frac{\sin CA}{\cos CA} = \frac{\dot{H}_{GM}}{\dot{Y}_{GM}}. \tag{33}$$

When rearranged into a form the computer can use, the equation is:

$$\dot{Y}_{GM} \sin CA - \dot{H}_{GM} \cos CA = 0. \tag{34}$$

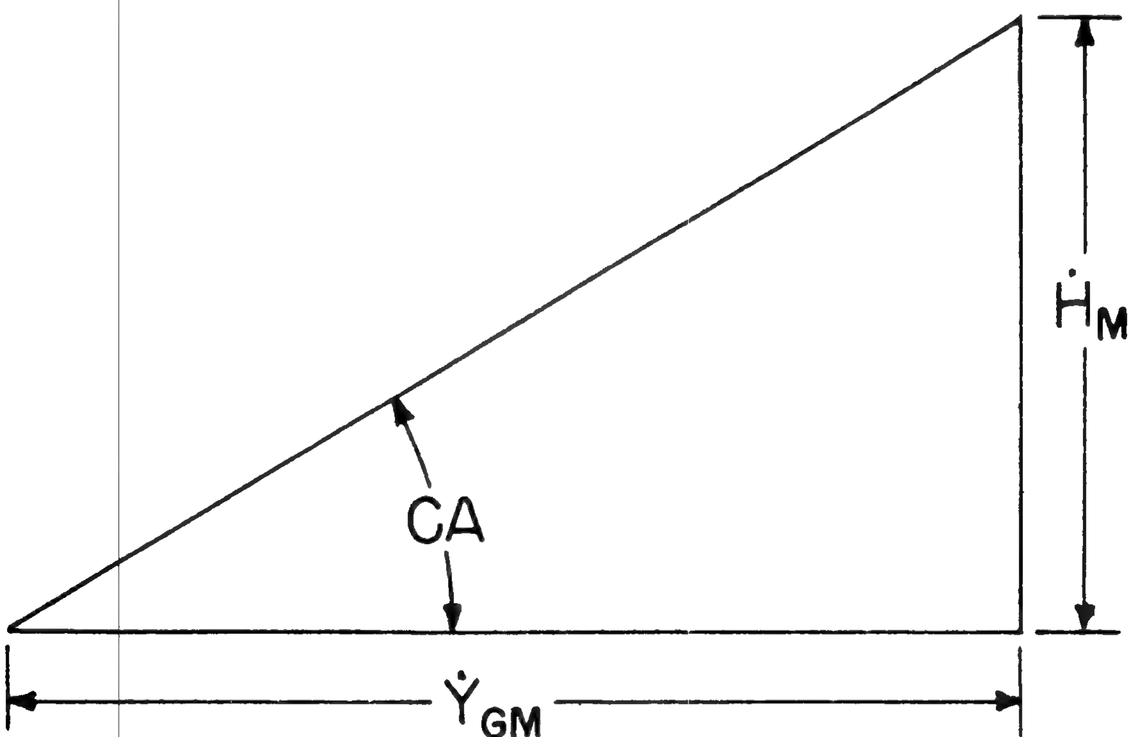


Figure 12. Trigonometric solution of the climb angle.

25. DETAILED OPERATION (TM 9-5000-26, p 70)

Since the component of missile velocity, H_M, along the earth vertical axis, H, is already parallel to the gyro vertical axis, it does not pass through the

missile rate converter, but is applied directly to a sin-cos CA card, CA2-4.75, as an input to the CA servo. Also the quantity $\dot{Y}_{GM}$ is applied to a sin-cos CA card, CA2-5.25, as an input to the CA servo. Taken from these sin-cos CA cards are the terms $+\dot{Y}_{GM}$ sin CA and $-\dot{H}_M$ cos CA. These terms are added by the CA amplifier. When $\dot{Y}_{GM}$ sin CA minus $\dot{H}_M$ cos CA equals zero, the input to the amplifier is zero and CA is correct. If the CA input to the amplifier is positioned for a value of CA which is too large, the term $\dot{Y}_{GM}$ sin CA is larger than the term $-\dot{H}_M$ cos CA. A negative voltage at the output of the CA amplifier causes the CA servo to decrease the value of CA until the input to the summing amplifier is again zero. The d-c output of the CA amplifier is used to control the output of a 400-cycle modulator. The modulator output is then amplified to drive the CA servo.

26. GEOMETRIC GAIN CONTROL

The TA potentiometer card in the feedback path of the CA amplifier is a geometric gain control. The potentiometer has a geometrical shape so that the output from the brush varies as the cosine of the turn angle. As the turn angle increases from zero to its gimbal limit (70°), if the missile speed remains the same, $\dot{H}_{GM}$ and $\dot{Y}_{GM}$ diminish while $\dot{X}_{GM}$ increases (fig 13). As $\dot{H}_{GM}$ and $\dot{Y}_{GM}$ become smaller, the difference voltage obtained from $\dot{Y}_{GM}$ sin CA - $\dot{H}_{GM}$ cos CA also decreases. ($\dot{Y}_{GM}$ sin CA - $\dot{H}_{GM}$ cos CA is the formula used by the CA servo to solve for climb angle.) As an example, if the turn angle increases from 10° to 20°, and missile velocity remains constant, the increase must be caused by the diminishing of $\dot{Y}_{GM}$ and $\dot{H}_{GM}$. Since these two velocity components have become smaller, the difference voltage from $\dot{Y}_{GM}$ sin CA - $\dot{H}_{GM}$ cos CA is smaller. Without geometric gain, the CA servo would not have as large an input to drive it, i.e., its sensitivity would have decreased. Therefore, without geometric gain control, sensitivity of the CA servo loop decreases as the turn angle increases. To keep the output of the CA servo large even though the input, $\dot{Y}_{GM}$ sin CA - $\dot{H}_{GM}$ cos CA, is getting smaller, the gain of the servo must increase as TA increases. The cosine of TA is the function used as feedback because the projection of the missile velocity upon the gyro reference plane varies as cos TA. This feedback is degenerative and becomes smaller as TA increases and as $\dot{Y}_{GM}$ sin CA - $\dot{H}_{GM}$ cos CA decreases. The effect in the amplifier is that the gain increases. When TA equals 0°, the gain is approximately 45. When TA equals 70°, the gain is approximately 130. The CA servo maximum speed is 33° per second, or 587 angular mils per second. In summary, the speed of the missile will vary only slightly, having little effect upon the climb angle, but the direction of the flight of the missile can vary as much as 70°. This change in direction or change of the turn angle would affect the CA servo if geometric gain were not used, since the velocity components, $\dot{Y}_{GM}$ and $\dot{H}_{GM}$, will vary inversely with the turn angle. Geometric gain control is necessary to prevent the sensitivity of the CA servo from being reduced. By using geometric

gain control, the CA servo solves for equal climb angles in the same length of time, regardless of the turn angle involved.

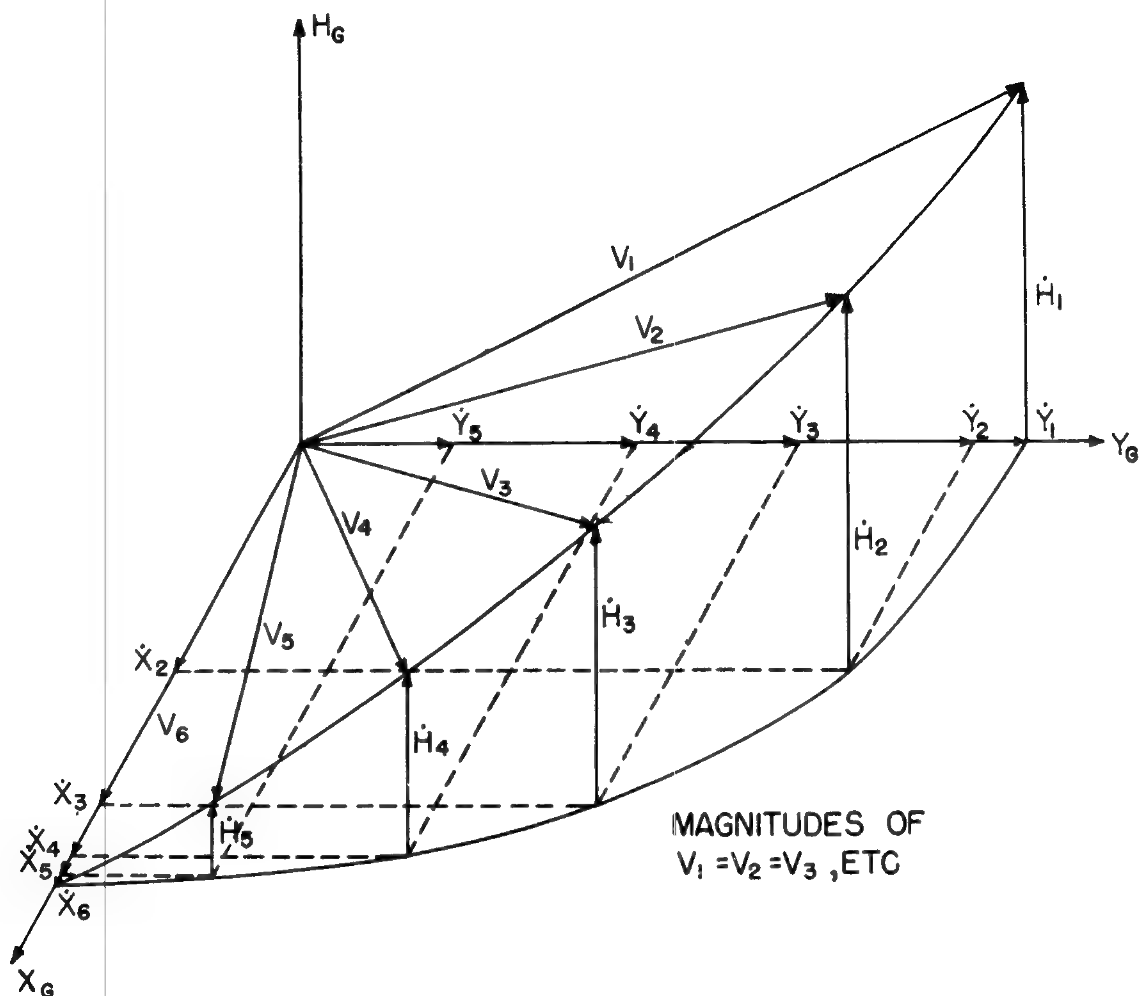


Figure 13. Projection of missile velocity on the gyro axes caused by a change of TA.

27. MECHANICAL OPERATION (TM 9-5000-26, pp 71 and 72)

The climb and turn angle servo assembly mechanical schematic shows the gearing, dials, and potentiometer containers of the CA and TA servos. The potentiometer marked R-1 contains CA potentiometers CA1-4.75 and CA1-5.25, and R-3 contains TA3-3.75, the TA geometric gain control potentiometer, which is in the feedback loop of the CA DC amplifier. The CA servomotor operates through a system of gears to rotate the brush arms of the potentiometers through the correct climb angle. The slip clutch permits the CA servomotor to turn without damaging the gears if some mechanical defect causes the gears to jam.

The excursion of the climb servo itself is unlimited. The value of the climb angle can be read through a window on the front of the climb and turn servo, using both coarse and fine dials to get an accurate reading.

Section IV. TURN ANGLE SERVO

28. GENERAL

The turn angle servo determines the turn angle of the missile. As was pointed out in the section on the climb angle servo, the steering errors are determined in the earth coordinate system. The steering errors must be related to the missile in flight. To do this, the steering errors are rotated through the climb and turn angles. This requires that the missile turn angle be determined.

29. MATHEMATICAL ANALYSIS

To calculate the turn angle of the missile, components of missile velocity in the missile velocity slant plane must be used. These are V_i, which lies along L_i, and $\dot{X}_{GM}$. The quantity $\dot{X}_{GM}$ can be obtained directly from the missile rate converter, but V_i must be calculated in terms of $\dot{Y}_{GM}$ and $\dot{H}_M$. Both $\dot{Y}_{GM}$ and $\dot{H}_M$ have components which lie along L_i (fig 14). The component of $\dot{Y}_{GM}$ is $\dot{Y}_{GM} \cos CA$. The component of $\dot{H}_M$ is $\dot{H}_M \sin CA$. Component V_i is equal to the sum of these two components. Thus, the equation for V_i is:

$$V_i = \dot{Y}_{GM} \cos CA + \dot{H}_M \sin CA. \qquad (35)$$

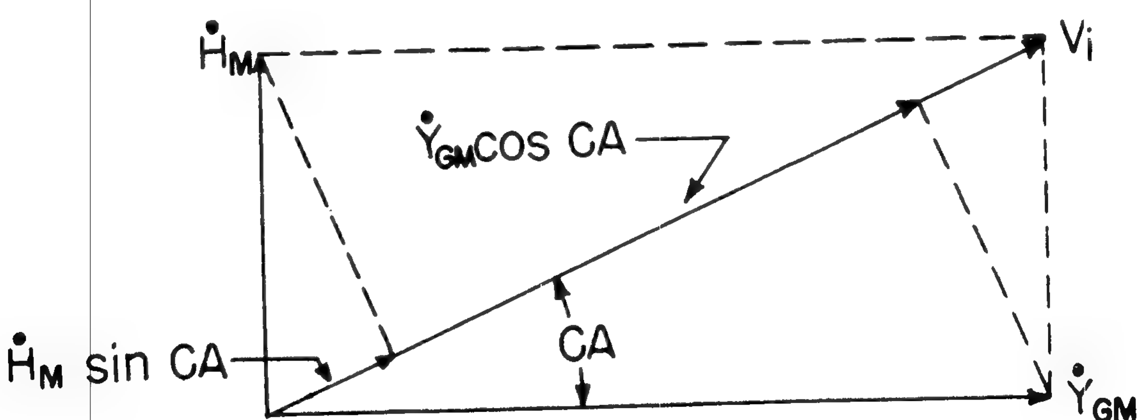


Figure 14. Solution for V_i.

The formula the computer uses to solve for the turn angle may be calculated by using the trigonometric solution (fig 15). The turn angle is calculated from the relation:

$$\tan TA = \frac{\dot{X}_{GM}}{V_i}, \tag{36}$$

and since

$$\tan TA = \frac{\sin TA}{\cos TA},$$

the equation may be written thus by substituting in the equation for V_i:

$$\frac{\sin TA}{\cos TA} = \frac{\dot{X}_{GM}}{V_i} = \frac{\dot{X}_{GM}}{\dot{Y}_{GM} \cos CA + \dot{H}_M \sin CA}. \tag{37}$$

When rearranged into a form the computer can use, the formula is:

$$\dot{Y}_{GM} \cos CA \sin TA + \dot{H}_M \sin CA \sin TA - \dot{X}_{GM} \cos TA = 0. \tag{38}$$

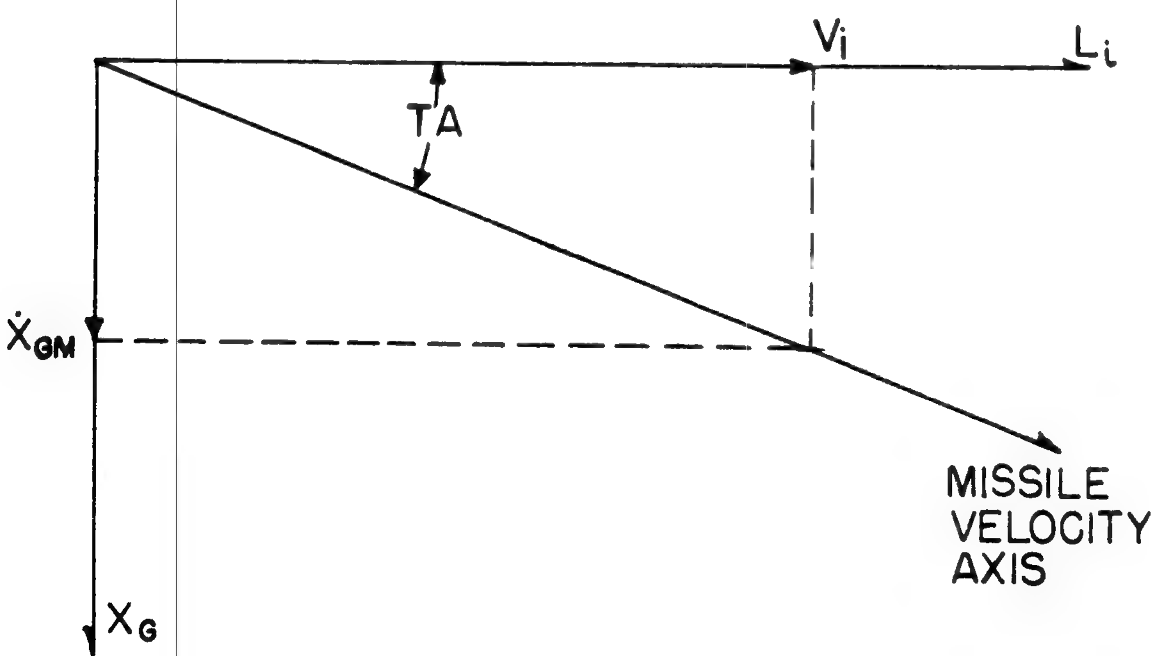


Figure 15. Determination of the missile turn angle.

30. DETAILED OPERATION (TM 9-5000-26, p 70)

Potentiometer brushes positioned by the CA servo develop the terms $\dot{H}_M$ sin CA and $\dot{Y}_{GM}$ cos CA, which are applied to sin-cos cards TA3-4.75 and TA3-5.25. These cards develop outputs $\dot{Y}_{GM}$ cos CA sin TA and $\dot{H}_M$ sin CA sin TA, which are summed in the input network of the TA amplifier with $-\dot{X}_{GM}$ cos TA. This input is from another TA potentiometer, TA3-4.25, which is fed by $\pm\dot{X}_{GM}$ from the $\pm\dot{X}_{GM}$ amplifiers. When:

$$\dot{Y}_{GM} \cos CA \sin TA + \dot{H}_M \sin CA \sin TA - \dot{X}_{GM} \cos TA = 0,$$

there is no output from the TA amplifier and the position of the TA servomotor output shaft represents the correct turn angle. The modulator, LPSA, and servomotor operate in the same manner as those in the CA servo loop. If the TA servo is positioned for a value of TA which is too large, then the term $\dot{Y}_{GM}$ cos CA sin TA + $\dot{H}_M$ sin CA sin TA will be larger than the term $\dot{X}_M$ cos TA. The sum of the voltages at the input of the TA amplifier is positive, and its output is negative. A negative voltage here decreases the turn angle. The servo turns until the sum of the input voltages is zero and the turn angle is then of the proper value. The TA servo does not need geometric gain control because the error voltages that actuate the TA servo system are unaffected by changes in the value of the climb angle. This can be understood more easily by examining the equation:

$$\tan TA = \frac{\dot{X}_{GM}}{V_i}, \tag{39}$$

which shows how the missile velocity components V_i and $\dot{X}_{GM}$ define the turn angle. Since both V_i and $\dot{X}_{GM}$ are located in the missile velocity slant plane, they obviously cannot be affected by angle CA, which the slant plane makes with the horizontal plane. Since V_i and $\dot{X}_{GM}$ are independent of CA, no geometric gain is necessary.

31. MECHANICAL OPERATION (TM 9-5000-26, pp 71 and 72)

The number of mils of angular rotation of the output shaft of the TA servomotor represents a certain value of turn angle. As the servomotor changes the position of the output shaft, the turn angle also changes value. This change is transmitted to the potentiometer brushes through a system of gears. The turn angle can be read on the coarse and fine indicating dials. Gear sizes, relative shaft speeds, and rotational directions for the turn servo are identical to those for the climb servo. The brushes of potentiometers R3 and R4 are rotated through the turn angle (71A3 and 71A7). The motor drives and TA limit switching are shown on the right-hand side of this schematic. The gimbal limit microswitches, S1 and S2, are physically located near R3. The cam is actually

on the shaft that turns the R3 potentiometer. This cam has been cut and positioned so that one or the other of the switches will close at 70° on either side of the gyro reference plane. Switch S1 is called the plus gimbal limit microswitch and when it closes, it energizes K126. Switch S2 is called the minus gimbal limit microswitch and energizes K127 (79B6). Assume that the target flies such a course (and this is highly improbable) that the intercept point is outside the +70° gimbal limit. The TA servo attempts to turn the missile so that it flies toward the intercept point, and the turn angle increases. At +70°, the cam attached to the potentiometer shaft closes microswitch S1, and K126 energizes. A voltage from the t-servo is sent through K126 to the fin order solver to turn the missile to keep it within the 70° limit. The missile had been turning to the right, so this order to the missile causes it to turn to the left. When TA is less than 70°, the microswitch opens and regular orders are again applied to the fin order solver. If the intercept point is still outside the limit, the missile again turns to the right and the sequence occurs again. When the turn angle reaches a gimbal limit, a light glows on the tactical control panel in front of the computer operator. This light is the left light of three in the bottom row and is marked GYRO LIM. The TA servo may continue to turn, and if the turn angle reaches 85° ± 2.8°, the microswitch, S3, on potentiometer R4 opens, placing resistor R5 in the ØC-to-neutral stator of the TA servomotor. Since the operation of the motor depends upon the magnitude of current in the stator coil, increased resistance in series with the coil reduces the current in the coil to such an extent that the motor speed is almost stopped. However, almost immediately the turn angle begins to get smaller as the missile turns back within the 70° limit, microswitch S3 closes, and the servo again speeds up. Therefore, S3 is in the circuit to protect the TA servomotor.

Section V. MISSILE VELOCITY METER

32. GENERAL

The missile velocity meter is a source of information for the tactical control officer. Circuits in the computer make available the missile velocity along the missile velocity axis in the form of a voltage analog. This information is applied to a metering circuit, which is calibrated so that the information is presented to the tactical control officer as a dial reading in yards per second.

33. MATHEMATICAL ANALYSIS (fig 16)

If the missile climb and turn angles are known, the missile velocity along the missile velocity axis may be calculated. Since $\dot{X}_{GM}$ and V_i have components which lie parallel to the missile velocity axis, they may be resolved into the terms $\dot{X}_{GM}$ sin TA and V_i cos TA;

$$\text{missile velocity} = \dot{X}_{GM} \sin TA + V_i \cos TA. \tag{40}$$

But:

$$V_i = \dot{Y}_{GM} \cos CA + \dot{H}_M \sin CA. \tag{41}$$

Substituting for V_i, it is seen that: missile velocity

$$= \dot{X}_{GM} \sin TA + \dot{Y}_{GM} \cos CA \cos TA + \dot{H}_M \sin CA \cos TA. \tag{42}$$

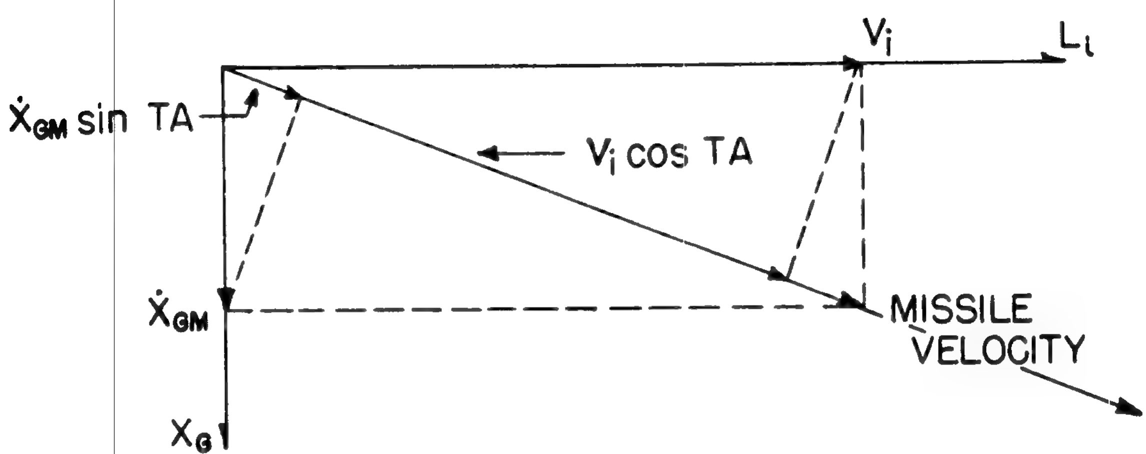


Figure 16. Solution for missile velocity.

34. DETAILED OPERATION (TM 9-5000-26, p 67)

The velocity of the missile is determined by summing the three terms: $\dot{H}_M$ sin CA cos TA from the TA potentiometer, TA3-4.75, which has as its inputs $\pm\dot{H}_M$ sin CA; $\dot{Y}_{GM}$ cos CA cos TA from TA potentiometer, TA3-5.25, which has as its inputs $\pm\dot{Y}_{GM}$ cos CA; and $\dot{X}_{GM}$ sin TA from TA potentiometer, TA3-4.25, which has as its inputs $\pm\dot{X}_{GM}$. These three terms are applied through large resistances, 0.698 megohms, to a low-resistance meter. The current through the meter represents the summation of the three terms. The meter is calibrated to read missile velocity directly. A 20-microampere current is equal to 2,000 knots; therefore, a 1-microampere current indicates a speed of 100 knots, which is approximately 115 miles per hour. Notice that the naval term knot has the dimensions of speed and not distance.

Section VI. RADAR-TO-RADAR PARALLAX UNIT

35. GENERAL

In the computation of steering commands to be sent to the missile, the computer must determine the rectangular coordinates, X, Y, and H, from the missile to the target. The origins of the rectangular coordinates which represent present position of the target and missile are the TTR and MTR. In figure 17, the target-tracking radar is shown as the origin of the earth coordinate system. The missile-tracking radar, the missile, and the target are pictured on the east axis. Note the available data for determining the distance between the missile and target. Voltages representing X_T, Y_T, and H_T, and X_M, Y_M, and H_M are obtained from the target and missile coordinate converters. If the computation is to be accurate, the distance between the two radars must be included in the calculation. This is done by voltages representing X_R, Y_R, and H_R, the rectangular coordinates of the missile-tracking radar, using the target-tracking radar as the origin.

36. DETAILED OPERATION (TM 9-5000-26, p 76)

Parallax information is set into the parallax unit by manually positioning three potentiometers. All of the potentiometer cards in this unit are in parallel and are centertapped to ground. The combined resistance of either R1 or R8 in parallel with the potentiometer card is 103.77 ohms. Because of the voltage divider action of this resistance, with R2 and R4 on the negative voltage side and R5 and R7 on the positive voltage side, 0.1647 volt appears across the potentiometers. With the scale factor of 1 millivolt per yard, this voltage amounts to 164.7 yards. Because of manufacturing tolerances, the voltage that may be picked off the potentiometer cards will vary very slightly in different Nike systems. For practical purposes, it is assumed that the maximum setting which may be made on the radar-to-radar parallax dials is 165 yards. This setting is represented by 0.165 volt, which is the total voltage that may be picked off the potentiometer card. The voltage is taken from the brush arms and sent to the steering switching relay panel shown at 61B12. In the steering switching relay panel, X_R, Y_R, and H_R are applied through contacts of relays K33 and K36 to the $\frac{X}{t}$, $\frac{Y}{t}$, and $\frac{H}{t}$ amplifier input networks shown in TM 9-5000-26, page 75. These amplifier input networks are components of the closing speed solver.

Section VII. CLOSING SPEED SOLVER

37. GENERAL

The closing speed solver calculates the desired or ideal closing velocity of the missile and target. This velocity represents the theoretical closing velocity which would be present if the missile and target were on exact collision courses. The actual closing velocity may be determined by adding the known velocities of the missile and target. By comparison of the actual and desired closing velocities, steering errors are determined. If the two velocities are equal, the missile is on the correct course; if they are not equal, a steering error exists. This error is converted into commands to steer the missile onto the correct trajectory.

38. MATHEMATICAL ANALYSIS

To compute the ideal closing velocity, the closing speed solver requires information regarding target and missile position and time to intercept. Present position data are supplied in rectangular coordinates from the target and missile coordinate converters, and time is applied as a mechanical shaft position from the time-to-intercept servo. Also, parallax information is supplied from the radar-to-radar parallax unit. Figure 17 is a representation of missile, target, and MTR positions relative to the TTR. For simplicity, only the X-coordinate is shown. The X rectangular coordinate of the distance between missile and target is the desired quantity. The target is shown approaching in the first quadrant. The following equation is derived from the figure.

$$X = X_T - X_R - X_M. \tag{43}$$

The quantity labeled X is always measured from the missile to the target. The other coordinates, Y and H, are obtained similarly:

$$Y = Y_T - Y_R - Y_M, \tag{44}$$

$$H = H_T - H_R - H_M. \tag{45}$$

To obtain the ideal closing velocity from the rectangular coordinates of missile and target positions, the known rectangular coordinates are divided by the remaining time to intercept, t. The outputs of the closing speed solver are obtained by solving the right side of the equations:

$$\frac{X}{t} = \frac{X_T - X_R - X_M}{t}, \tag{46}$$

$$\frac{Y}{t} = \frac{Y_T - Y_R - Y_M}{t}, \tag{47}$$

$$\frac{H}{t} = \frac{H_T - H_R - H_M}{t}. \tag{48}$$

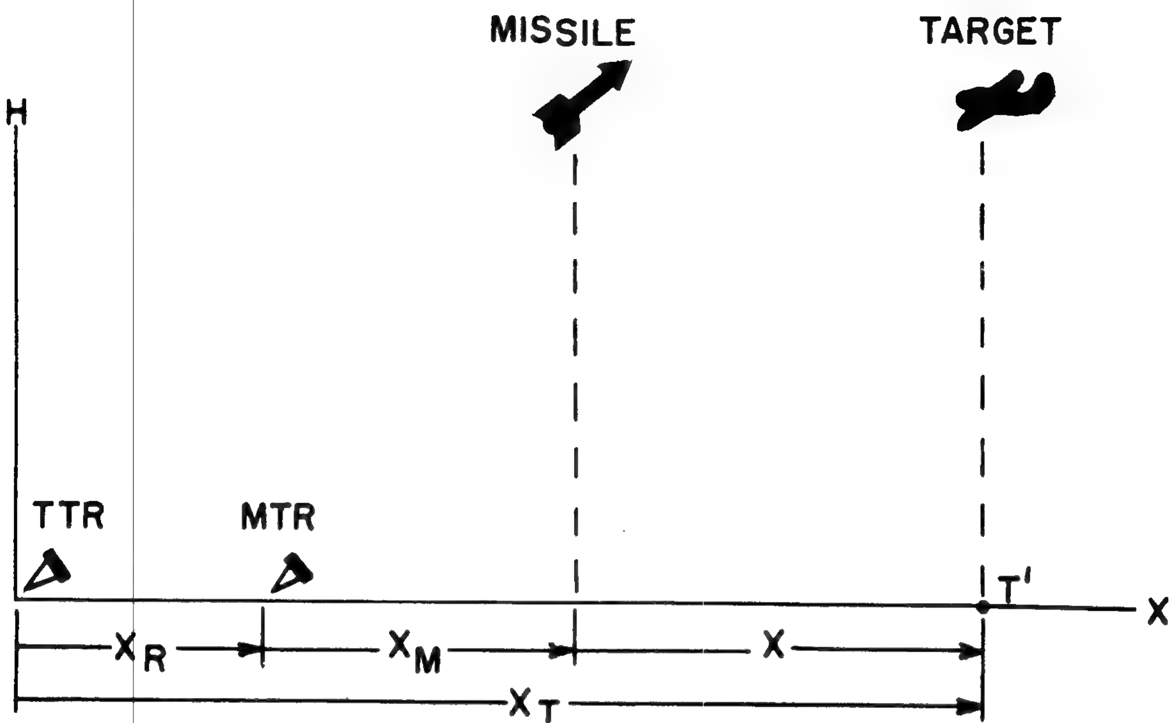


Figure 17. Determination of distance between missile and target.

39. SIMPLIFIED FUNCTIONAL OPERATION (fig 19)

Assume that the conditions shown in figure 17 are still current.

a. Inputs. Note the inputs to the $\frac{X}{t}$ input network. For the situation shown in figure 17, X_T is a positive quantity and, therefore, is represented by a negative voltage on terminal 4 of the input network. The quantities X_M and X_R are positive and are represented by positive voltages at terminals 5 and 6, respectively. These polarities are chosen because a positive voltage representing $\frac{X}{t}$ is desired at the output of the $\frac{X}{t}$ amplifier for the conditions of figure 17. Polarity inversion occurs in the DC amplifiers.

b. Division by time. To divide the distance X by time to intercept to obtain $\frac{X}{t}$, a potentiometer network is incorporated in the feedback loop of the DC amplifier. The brush arm of the potentiometer is connected to and driven by the time-to-intercept servomotor shaft. Figure 18 shows a simplified version of the $\frac{X}{t}$ amplifier shown at 75A1. E_{in} is a negative voltage because X is a positive quantity in figure 17. E_{out} is a positive voltage representing the ideal closing velocity $\frac{X}{t}$. In this amplifier, the output is determined by the equation:

$$E_{out} = E_{in} \frac{R_B}{R_{in}} \frac{R_1 + R_2}{R_2} . \tag{49}$$

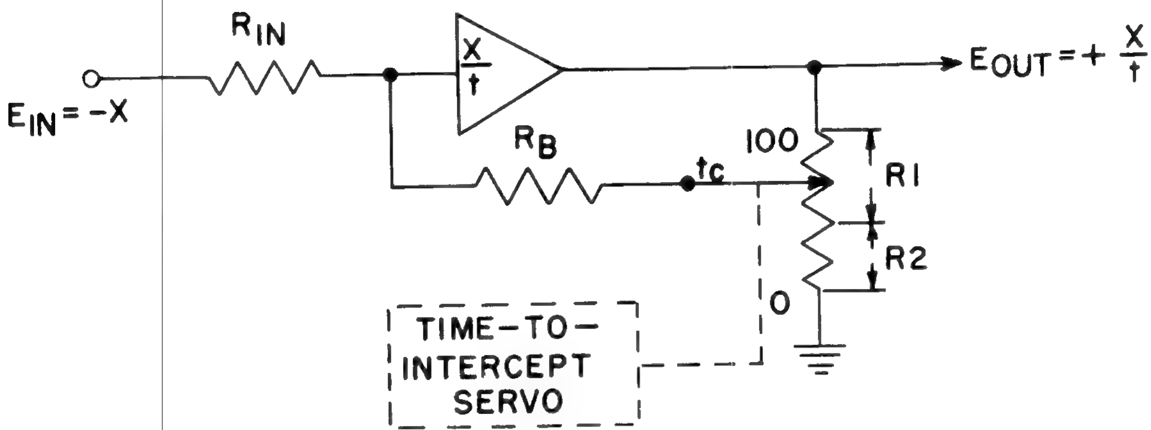


Figure 18. Dividing X by t to obtain $\frac{X}{t}$.

The output will increase as the time to intercept decreases. The mathematical function performed by this amplifier is division by a quantity less than 1, which is essentially multiplication by a quantity greater than 1.

c. Time cards. There are two time-to-intercept cards in the feedback loop (fig 19). The card marked t_c is a coarse potentiometer card, while that marked t_f is a fine potentiometer card. Both cards are linear. The total length of the coarse card represents 100 seconds. The fine card represents only 25 seconds, and since it is physically longer than one-fourth of the coarse card, it provides finer granularity and increased accuracy in positioning the time servo. When t reaches 24 seconds as time to intercept decreases, K1 FINE is energized by a cam-operated microswitch in the time servo, replacing the coarse card with the fine card in the feedback circuit. Notice that a different feedback resistor is used when fine card switching occurs. This is necessary because the coarse potentiometer card represents four times as many seconds as does the fine card.

The feedback resistor used with the t_c potentiometer is one-fourth the size of that used with the t_f potentiometer.

d. Scale factor. The scale factor of the input voltages applied to the $\frac{X}{t}$ amplifier is 1 millivolt per yard. The determination of the output scale factor involves the gain of the amplifier circuit. The input is represented by the scale factor 1 millivolt per yard. The gain of the amplifier is expressed by:

$$-E_{out} = E_{in} \frac{R_B}{R_{in}} \quad \frac{R_1 + R_2}{R_2} . \qquad (50)$$

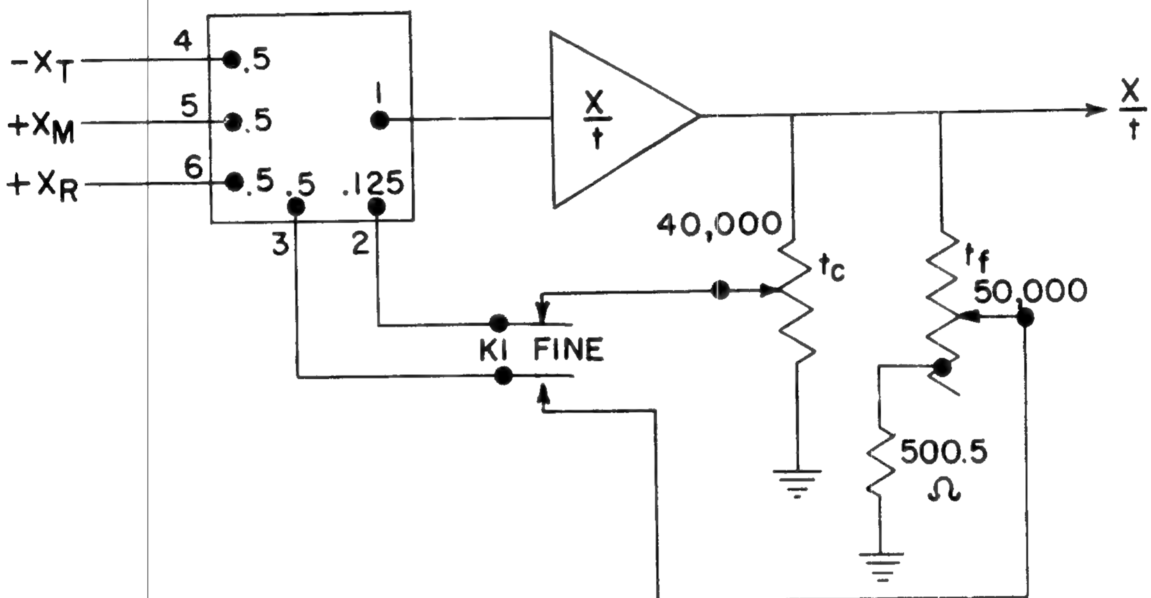


Figure 19. Closing speed solver, simplified schematic.

The multiplier, $\frac{R_1 + R_2}{R_2}$, is concerned with either the t_c or t_f potentiometer card in the amplifier feedback loop. Consider a 1-second time of flight. The entire length of the card, $R_1 + R_2$, equals 100 seconds, and in the following formula R_2 is t and represents 1 second:

$$-E_{out} = E_{in} \times \frac{R_B}{R_{in}} \times \frac{100}{t} , \qquad (51)$$

or: output scale factor = 1 mv/yd x $\frac{0.125}{0.5}$ x $\frac{100}{1}$ = 25 mv/yd/sec. In the case just stated, the coarse-time card was considered. With the fine-time card a

similar situation results: output scale factor = 1 mv/yd x $\frac{0.5}{0.5}$ x $\frac{25}{1}$ or 25 mv/yd/sec. Therefore, the output scale factor of the closing speed solver is 25/mv/yd/sec. Note that in the case for the coarse potentiometer card, the feedback resistor is 0.125 megohm and for the fine card the feedback resistor is 0.5 megohm.

e. Time potentiometer tap. The tap with the 500-ohm resistor to ground on the t_f potentiometer is placed at the 1/4-second position. An examination of the term $\frac{X}{t}$ reveals that as both X and t decrease, a point will be reached where the term will not give an exact solution. This condition exists when t is zero. The effect of adding this resistor to the circuit is to cause time as a divisor to appear constant from 0.25 second to zero time. This holds the gain of the $\frac{X}{t}$ amplifier constant from 0.25 second to zero time, during which time the output is applied to the apparent miss distance circuit. Another desirable effect of controlled gain at zero time is that it prevents the DC amplifier from going into an overload condition.

40. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, p 75)

Note the three inputs, $-X_T$, $+X_M$, and $+X_R$, and the two different values of feedback resistors at terminals 3 and 2 of the $\frac{X}{t}$ input network. The $\frac{X}{t}$ amplifier (75A2 of 2y) is a 3-stage, DC amplifier. At MA + 4, steer relay K4 (75B2 of 2y) energizes, causing potentiometer T_C-15A or T_F-10 (75B4) to be placed into the feedback network, depending upon the operation of relay K1 FINE (75B2). Relay K1 energizes when time to intercept has decreased to 24 seconds. The operation of the contacts of this relay causes the fine potentiometer card to be connected in the feedback loop in place of the coarse card. At the output of the $\frac{X}{t}$ amplifier, note the lead directed to 16C4 (29C6). This lead is connected to a zero-check switch and zero-check meter located in the computer amplifier cabinet. Note the contacts of the burst enable relay, K4 (75A4). This relay energizes when the time to intercept has decreased to 0.25 second. Relay K4 operates in conjunction with the event recorder to record the error at burst. At 75B3, locate the velocity meter which receives $\frac{X}{t}$ as an input. This meter is used in the tracking tests of the computer. For simplicity, only the circuits concerned with the X-coordinate have been considered. The $\frac{Y}{t}$ and $\frac{H}{t}$ amplifiers and their associated circuits operate in the same manner as the $\frac{X}{t}$ circuit.

41. ILLUSTRATIVE PROBLEM

a. Problem. The scale factor for the inputs representing missile and target position, X_M and X_T, is 1 mv/yd/sec. The output scale factor is 25 mv/yd/sec. To illustrate the operation of this circuit, assume the following:

$$X_T = 50,000 \text{ yards east,}$$

$$X_M = 7,000 \text{ yards east,}$$

$$X_R = 50 \text{ yards east,}$$

$$t = 50 \text{ seconds.}$$

The conditions of this problem are similar to those found in figure 17. Substituting this information in the basic equation:

$$X = X_T - X_R - X_M.$$

The position difference of missile and target is:

$$X = 50,000 - 50 - 7,000 = 42,950 \text{ yards.}$$

To determine the ideal closing velocity, the position difference is divided by time. The result of this division is:

$$\frac{X}{t} = \frac{42,950}{50} = 859 \text{ yards per second.}$$

b. Problem using voltage analogs. Checking this computation through the circuit using the scale factors should produce the same result. To do this, determine the input voltages to the $\frac{X}{t}$ amplifier. Using a scale factor of 1/mv/yd, they are:

$$X_T = -50 \text{ volts,}$$

$$X_R = +0.05 \text{ volt,}$$

$$X_M = +7 \text{ volts.}$$

Therefore, the sum of the inputs to the $\frac{X}{t}$ amplifier is -42.95 volts, which represents the missile-to-target distance, X.

c. Amplifier gain. The gain of the amplifier must be known to determine the output voltage. The gain is found by dividing the feedback resistance by the input resistance and multiplying this fraction by the ratio of the output voltage to the feedback voltage. This results in a gain of:

$$\frac{0.125}{0.5} \times \frac{100}{50} = 0.5.$$

The fraction $\frac{100}{50}$ is from positioning the time-to-intercept servo at 50 seconds. The total time available from potentiometer T_C-15A (75B4) is 100 seconds. Therefore, the brush arm on this card is at the midposition. The top of the card represents 100 units of resistance, while the brush arm position represents 50 units of resistance. Consequently, the ratio of output voltage to feedback voltage is $\frac{100}{50}$. If the gain of the amplifier is 0.5 and the input voltage is -42.95 volts, the output voltage is +21.475 volts. The scale factor on the output of the $\frac{X}{t}$ amplifier is known to be 25 mv/yd/sec. Therefore, this output represents:

$$\frac{21.475}{0.025} = 859 \text{ yards per second.}$$

The result obtained from the circuit carries the same sign as the result obtained mathematically, since a positive output from the $\frac{X}{t}$ amplifier indicates a positive quantity.

Section VIII. STEERING ERROR SOLVER

42. GENERAL

The steering error solver compares the ideal closing velocity components ($\frac{X}{t}$, $\frac{Y}{t}$, $\frac{H}{t}$) from the closing speed solver with the actual velocity components ($\dot{X}_T - \dot{X}_M$, $\dot{Y}_T - \dot{Y}_M$, and $\dot{H}_T - \dot{H}_M$) from the target-steering and missile differentiators. The inputs to the steering error solver are as follows: $\frac{X}{t}$, $\frac{Y}{t}$, and $\frac{H}{t}$ from the closing speed solver; $\dot{X}_T$, $\dot{Y}_T$, and $\dot{H}_T$ from the target-steering differentiator; and $\dot{X}_M$, $\dot{Y}_M$, and $\dot{H}_M$ from the missile differentiator. The outputs are voltages which represent steering errors in terms of velocity components S_X, S_Y, and S_H. The inputs from the closing speed solver have a scale factor of 25 mv/yd/sec. The inputs from the target-steering and missile differentiators have a scale factor of 12.5 mv/yd/sec. Generally, the steering error solver is composed of DC amplifiers which act to sum the voltage inputs.

43. MATHEMATICAL ANALYSIS

To consider the mathematical operation of the steering error solver, the student should first examine the computation of the actual closing velocity of the missile and target. This is done by subtracting the missile velocity, as obtained by the missile differentiator, from the target velocity, as obtained from the target-steering differentiator. Figure 20 shows the interception of a target by a Nike missile. Vectors representing the actual velocity components of missile and target are labeled $\dot{X}_M$ and $\dot{X}_T$, respectively. The resultant of the subtraction

of these two velocity components is the actual closing velocity component, $\dot{X}$. The equation for $\dot{X}$ is:

$$\dot{X} = \dot{X}_T - \dot{X}_M. \qquad (52)$$

Note that for the case of figure 20, $\dot{X}_T$ is a negative quantity because the target is proceeding in a westerly direction. Conversely, $\dot{X}_M$ is a positive quantity because the missile is traveling eastward. The vector representing $\dot{X}$ is pointing westward (from the target) and the vector representing $\frac{X}{t}$ is pointing eastward (from the missile). The next step is the comparison of $\dot{X}$ and $\frac{X}{t}$, the actual and ideal closing velocity components. These quantities are added in the steering error solver and the resultant is called S_X. Stated in an equation:

$$S_X = \dot{X} + \frac{X}{t}. \qquad (53)$$

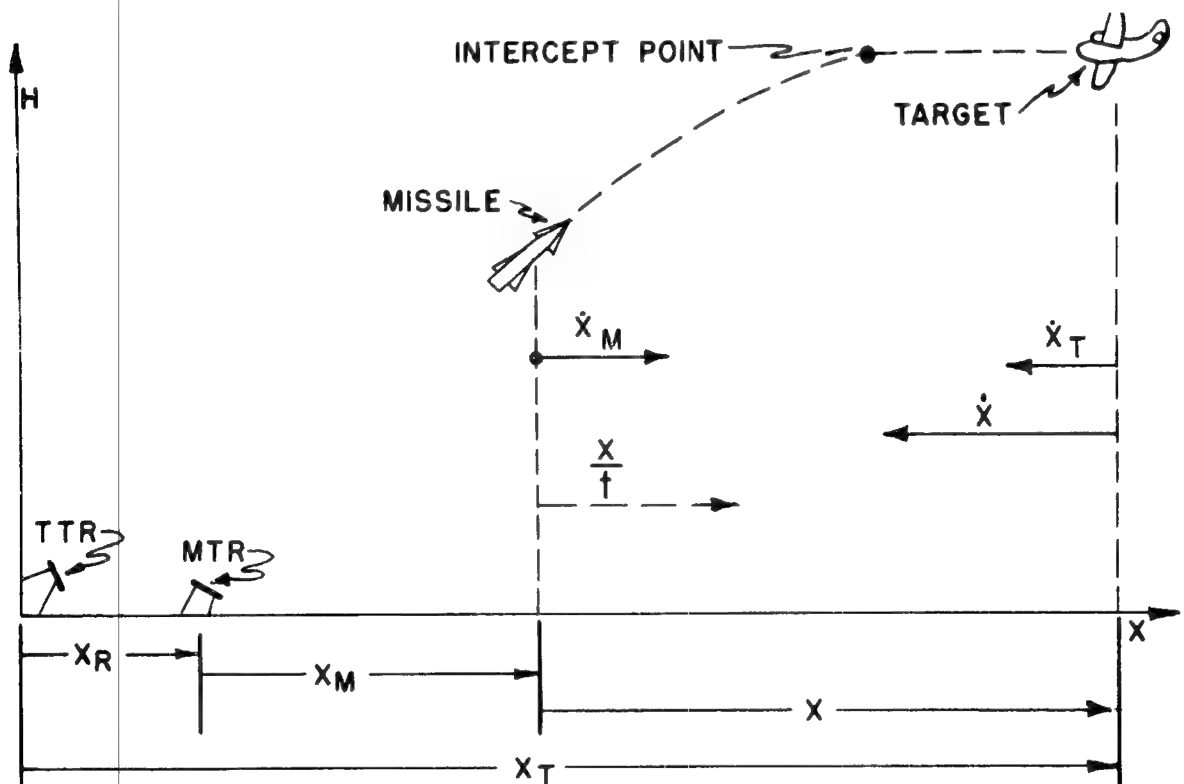


Figure 20. Comparison of ideal and actual closing velocities.

In figure 20, $\dot{X}$ and $\frac{X}{t}$ are shown exactly equal and opposite, indicating that the missile is on the correct intercept trajectory. Since the vectors representing $\dot{X}$ and $\frac{X}{t}$ are equal and opposite in this case, S_X is zero. If, under other

conditions, S_X is not zero, the missile is not on the correct trajectory, and a steering error exists. The Y-coordinate is treated similarly:

$$\dot{Y} = \dot{Y}_T - \dot{Y}_M, \tag{54}$$

and

$$S_Y = \dot{Y} + \frac{Y}{t}. \tag{55}$$

The actual closing velocity component is $\dot{Y}$. S_Y is the steering error component. The equation representing the steering error in the vertical or H-direction must be modified to allow compensation for the effect of gravity upon the missile. This equation is:

$$S_H = \dot{H} + \frac{H}{t} + \quad \frac{1}{4} + \frac{1}{6} gt. \tag{56}$$

The $\frac{1}{4} + \frac{1}{6}$ gt provides the compensation necessary for the effect of gravity. In developing the steering circuits for the computer, a special missile trajectory had to be selected, and compensation for gravity effects had to be included to define the selected trajectory. Three possible trajectories were considered: a 0g lift trajectory, a 1g lift trajectory, and a $\frac{1}{2}$g lift trajectory.

44. COMPARISON OF TRAJECTORIES

a. <u>0g lift trajectory</u>. To accomplish the 0g lift trajectory, the OT (on trajectory) signal has to be received when the missile has dived so that it is aimed toward an imaginary intercept point in space (IP_f) above the actual intercept point (IP) a distance equivalent to $\frac{1}{2}gt^2$ (fig 21). This term is equal to the distance the missile will fall in t time because of the effect of gravity. Once the missile reaches on trajectory, it drops to the IP as time to intercept decreases to zero. The gravitational force acting on the missile causes the missile to have a 1g downward acceleration. Since the distance $\frac{1}{2}gt^2$ decreases with time, it is evident that, with decreasing time to intercept, the IP_f is continually dropping toward the IP, and at time zero, the IP_f and the IP are in the same position. The advantage of this trajectory is that after OT is received, there is no requirement for a lift order to be constantly applied to keep the missile on trajectory, thus allowing minimum drag on the missile. The disadvantage of this trajectory is that the missile climbs to high altitudes for long-range targets, thus reducing maneuverability, and increasing time to intercept.

b. <u>1g lift trajectory</u>. To accomplish the 1g lift trajectory, the OT signal has to be received when the missile has dived so that it is aimed toward the IP (fig 22). Under ideal conditions the missile is then steered along a straight line path to the IP. This requires that a climb order be constantly applied after OT is received to oppose the downward pull of gravity acting on the missile. An

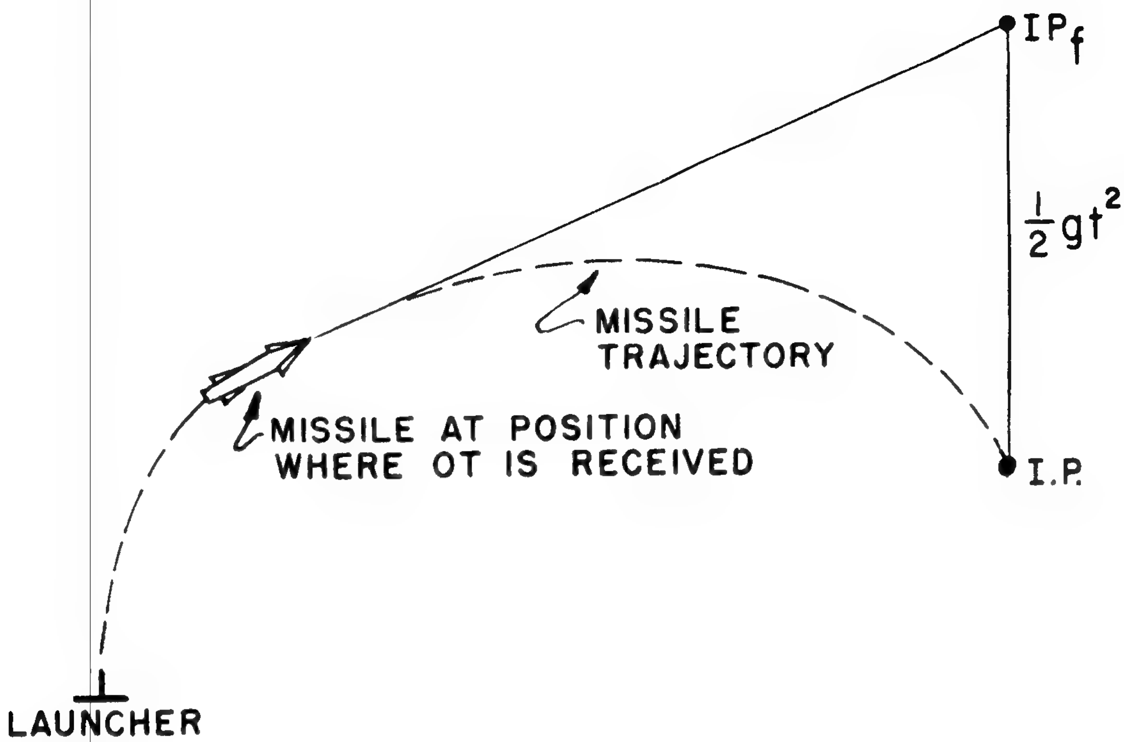


Figure 21. A 0g lift trajectory.

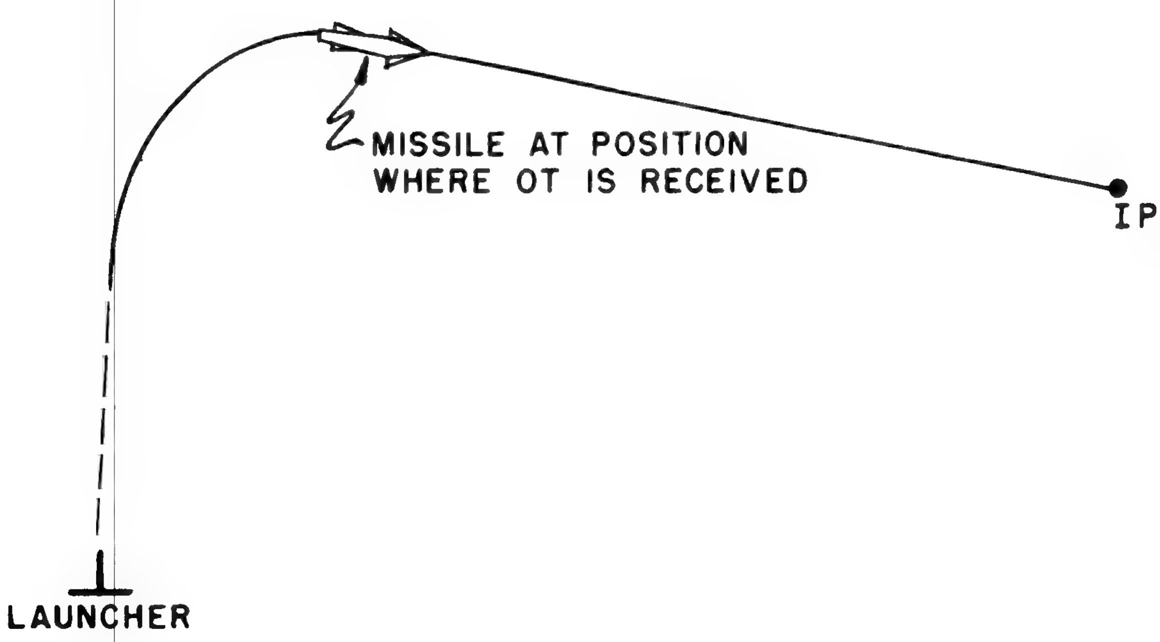


Figure 22. A 1g lift trajectory.

advantage of this trajectory is that it gives a shorter time to intercept. The disadvantage of this trajectory is that a 1g lift order must be constantly applied to the missile to keep it on trajectory with minimum pitch oscillations. The constantly applied lift order increases drag on the missile and results in reduced speed and maneuverability and shortened maximum effective range.

c. 1/2(g) lift trajectory. The 1/2(g) lift trajectory represents a compromise between the other two trajectories. It uses the advantages of one type trajectory to minimize the disadvantages of the other. To accomplish the 1/2(g) lift trajectory, the OT signal has to be received when the missile has dived until it is aimed toward an imaginary intercept point, IP_f, a distance equivalent to $1/4(gt^2)$ above the IP (fig 23). This is equal to one-half the distance the missile will fall in t time. From OT until intercept, a climb order must be constantly applied to oppose one-half of the gravitational force pulling downward on the missile. By countering one-half of the gravitational force acting on the missile, the missile is allowed to drop the distance $1/4(gt^2)$ between the IP_f and the IP as time to intercept decreases to zero. The advantage of this trajectory is that the missile flies low enough so that maneuverability is not sacrificed, and yet not so low that drag on the missile fins is excessive. This is the trajectory used for the Nike missile. The 1/4(gt) in formula (56) is used as a bias voltage to define

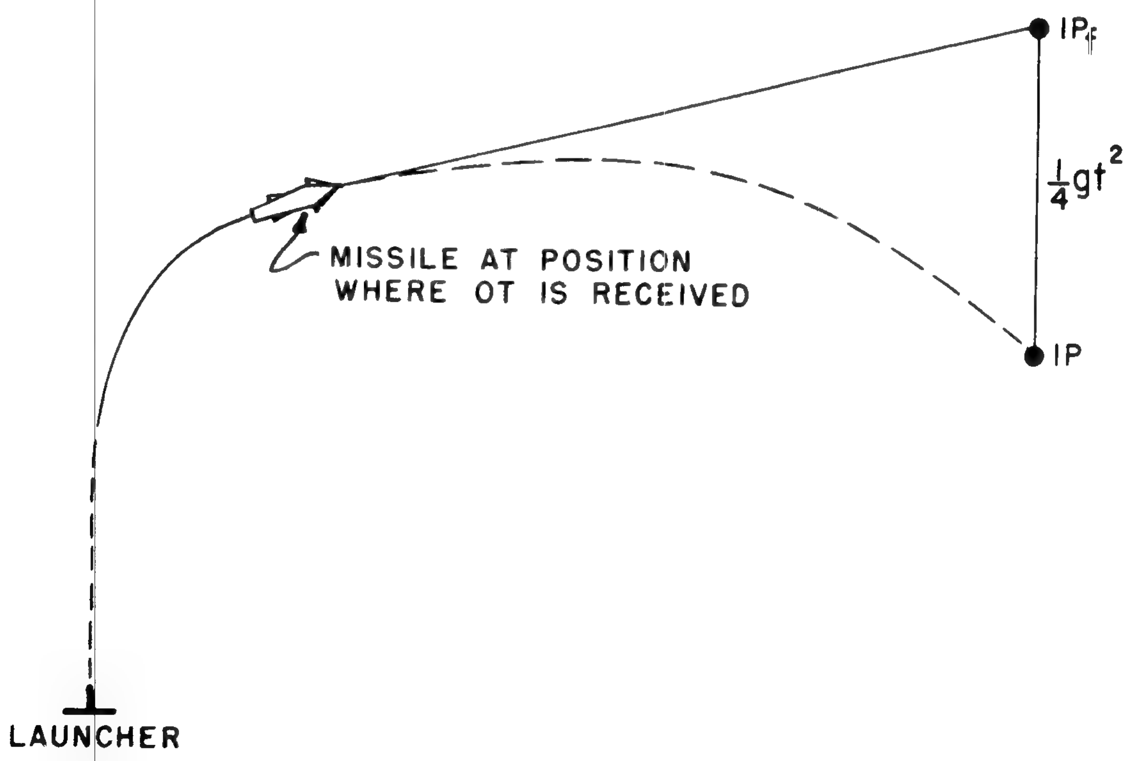


Figure 23. A $\frac{1}{2}$g lift trajectory.

the position of the IP_f above the IP, and is needed to develop the OT signal. Thus, when $\frac{H}{t} + H + \frac{1}{4}gt$ is equal to zero, the missile will be on the correct intercept trajectory. The $\frac{1}{6}gt$ is added after OT to develop the $\frac{1}{2}g$ lift order sent to the missile. This steers the missile smoothly on a dropping course to the IP, eliminating large pitch oscillations.

45. DETAILED OPERATION (TM 9-5000-26, p 75)

a. S_X and S_Y amplifiers. The inputs to the $-S_X$ and $-S_Y$ networks are similar. Consider the $-S_X$ network for simplicity. The input at terminal 3 is derived from the $\frac{X}{t}$ amplifier (75A2), and represents a component of the ideal closing velocity of missile and target. Note that the voltage input is positive if the target is east of the missile. This is the condition shown in figure 20. At terminals 4 and 5, the actual velocities of target and missile enter the $-S_X$ amplifier input network. The two voltages representing $+\dot{X}_T$ and $-\dot{X}_M$ come from the $+\dot{X}_T$ amplifier (47B11), and the $-\dot{X}_M$ amplifier (66C3). The voltage at terminal 4 representing X_T is negative if the target is traveling toward the west as was the case in figure 20. The combination of $-\dot{X}_M$ and $+\dot{X}_T$ are summed with the positive value of $\frac{X}{t}$. As was stated previously, no steering error is present if the sum is zero. Note the values of the input and feedback resistors of the $-S_X$ amplifier circuit. The feedback resistor is 1 megohm, as is the input resistor for the voltage representing $\frac{X}{t}$. The input resistors at terminals 4 and 5 are only 0.5 megohm. The different values balance the scale factors of the three input voltages. If these voltages are to be compared successfully, the scale factor must be the same for all three. However, the scale factor for $\dot{X}_M$ and $\dot{X}_T$ is 12.5 mv/yd/sec and for $\frac{\dot{X}}{t}$ it is 25 mv/yd/sec. By the choice of input resistors as indicated for the $\dot{X}_M$ and $\dot{X}_T$ voltages, their scale factors may be considered to be doubled according to the formula:

$$-E_{out} = E_{in} \frac{R_B}{R_{in}} . \qquad (57)$$

In this way, the output scale factors for the three inputs are the same and the summation may be made. The $-S_Y$ and $-S_H$ input circuits use the same arrangement and operate similarly. The next step in the problem solved by the computer steering section is to convert the steering errors from components along the earth axes to components along the gyro axes, X_G, Y_G, and H_G. To do this, it is necessary to supply the steering error converter with positive and negative values of S_X, S_Y, and S_H, which is done by adding three extra amplifiers ($+S_X$, $+S_Y$, and $+S_H$). These amplifiers perform simple sign inversion without multiplication or division. Positive and negative values of S_X S_Y, and S_H are sent to A_G sine-cosine potentiometers in the steering error converter.

b. $-S_H$ amplifier. The $-S_H$ amplifier requires special consideration. It receives ideal and actual closing velocities in a manner similar to the $-S_X$ and $-S_Y$ input networks. These inputs enter at terminals 3, 4, and 5. Also, a bias voltage enters at terminal 6. This bias is from a voltage divider on the output of the +t-amplifier (83C7). The voltage output of the +t-amplifier represents time to intercept at a scale factor of 1 volt per second. Locate the voltage divider consisting of resistors R138, R139, and R140. There is a tap to ground at the junction of R138 and R139, and the input to terminal 6 is taken at the junction of R139 and R140. Relay K32 is an on-trajectory locking relay, which energizes as soon as the missile reaches its proper trajectory at the end of the 7g dive. Before this time, the input at terminal 6 of the $-S_H$ amplifier is derived from the voltage divider consisting of R139 and R140. This input represents the quantity 1/4(gt), and can be solved for in volts by the equation:

$$\frac{1}{4}gt = +t \times \frac{51,100}{151,100} = +0.338t \text{ volts.} \tag{58}$$

This voltage is for aiming the missile a distance $1/4(gt^2)$ above the intercept point. As soon as ON TRAJECTORY is detected, relay K32 is energized, removing the ground from the junction of R138 and R139. The new voltage divider produces an increased output representing $(\frac{1}{4} + \frac{1}{6})gt$, which can be solved by the equation:

$$(\frac{1}{4} + \frac{1}{6})gt = +t \times \frac{129,800}{229,800} = +0.564t \text{ volts.} \tag{59}$$

The input has been increased by 1/6(gt). After ON TRAJECTORY has been received, this quantity causes the missile to fly a 1/2(g) lift trajectory. See 75D6 terminal 6 of the $-S_H$ input network. Notice that the input resistor is 5 megohms and that the feedback resistor is only 1 megohm. This provides the input with a multiplication factor of $\frac{1}{5}$.

46. ILLUSTRATIVE PROBLEM

To show the operation of the steering error solver with an illustrative example, consider the following data as known:

t = 60 seconds

X_T = +58,100 yards

Y_T = +58,100 yards

H_T = +20,000 yards

$\dot{X}_T$ = -200 yd/sec (traveling east to west)

$\dot{Y}_T$ = -200 yd/sec (traveling north to south)

$\dot{H}_T$ = 0 yd/sec

X_M = +10,000 yards

Y_M = +10,000 yards

H_M = +10,000 yards

X_R = +100 yards

Y_R = +100 yards

H_R = 0 yards

$\dot{X}_M$ = +300 yd/sec (traveling west to east)

$\dot{Y}_M$ = +600 yd/sec (traveling south to north)

$\dot{H}_M$ = +300 yd/sec (ascending)

1g = 10.7 yd/sec/sec.

From this information, the computer must determine any steering errors in the present trajectory of the missile. The first step is to determine position difference coordinates:

$$X = X_T - X_M - X_R = 58,100 - 10,000 - 100 = 48,000 \text{ yards},$$

$$Y = Y_T - Y_M - Y_R = 58,100 - 10,000 - 100 = 48,000 \text{ yards},$$

$$H = H_T - H_M - H_R = 20,000 - 10,000 = 10,000 \text{ yards}.$$

Next, the ideal closing velocities are computed:

$$\frac{X}{t} = \frac{48,000}{60} = 800 \text{ yd/sec},$$

$$\frac{Y}{t} = \frac{48,000}{60} = 800 \text{ yd/sec},$$

$$\frac{H}{t} = \frac{10,000}{60} = 166.7 \text{ yd/sec}.$$

The actual closing velocities are then arrived at:

$$\dot{X} = \dot{X}_T - \dot{X}_M = -200 - 300 = -500 \text{ yd/sec},$$

$$\dot{Y} = \dot{Y}_T - \dot{Y}_M = -200 - 600 = -800 \text{ yd/sec},$$

$$\dot{H} = \dot{H}_T - \dot{H}_M = 0 - 300 = -300 \text{ yd/sec}.$$

With both ideal and actual closing velocities available, the steering errors in the three earth coordinates are:

$$S_X = \frac{X}{t} + \dot{X} = 800 - 500 = +300 \text{ yd/sec},$$

$$S_Y = \frac{Y}{t} + \dot{Y} = 800 - 800 = 0 \text{ yd/sec},$$

$$S_H = \frac{H}{t} + \dot{H} + \frac{1}{4} + \frac{1}{6}\, gt = 166.7 - 300 + \frac{5}{12}(10.7 \times 60) = 134.2 \text{ yd/sec}.$$

From the steering errors indicated above, it is possible to analyze the corrections that must be made. Along the X-axis the steering error is +300 yards per second, a positive steering error. Since this polarity is positive, the computer must issue an order causing the missile to turn to the east, increasing its X-component of velocity. The positive value of S_H indicates that the missile trajectory would pass below the intercept point. The computer must issue a climb order to increase the velocity of the missile along the H-axis.

Section IX. STEERING ERROR CONVERTER

47. GENERAL

The steering error converter converts the steering error components derived from the steering error solver from earth axes to missile axes.

48. CONVERSION FROM EARTH TO GYRO COORDINATES (fig 24)

Since the vertical steering error, S_H, is equal to S_{GH}, only the mathematics of the conversion of S_X and S_Y to S_{GX} and S_{GY} need be discussed. Figure 24 shows the basic form of the coordinate conversion problem. S_Y is a positive steering error component along the earth Y-axis. The gyro axes, Y_G and X_G, and the gyro azimuth angle, A_G, are shown. This angle is measured between

the Y-earth-axis and the Y_G axis. The angle measured between the X-earth-axis and the X_G axis is also equal to A_G because the X_G axis is perpendicular to the Y_G axis and the X-axis is perpendicular to the Y-axis. Project the vectors representing S_X and S_Y on the X_G and Y_G axes. These projections produce four components, two derived from S_X and two from S_Y. Those derived from S_X are S_X cos A_G (along the X_G axis) and S_X sin A_G (along the Y_G axis), while the components from S_Y are S_Y cos A_G (along the Y_G axis), and S_Y sin A_G (along the X_G axis). Consider the transformation of S_X. The component lying along the X_G axis is positive going and equals S_X cos A_G. The component lying along the Y_G axis is positive going and equals S_X sin A_G. The latter expression may be obtained directly since, by geometry, the angle opposite S_X sin A_G is equal to A_G. Similarly, S_Y is converted into its two components. S_Y sin A_G lies along the X_G axis and is negative going. S_Y cos A_G lies along the Y_G axis and is positive going. The steering errors along the X_G and Y_G axes must be summed to give S_{GX} and S_{GY}. Expressed as equations:

$$S_{GX} = S_X \cos A_G - S_Y \sin A_G, \tag{60}$$

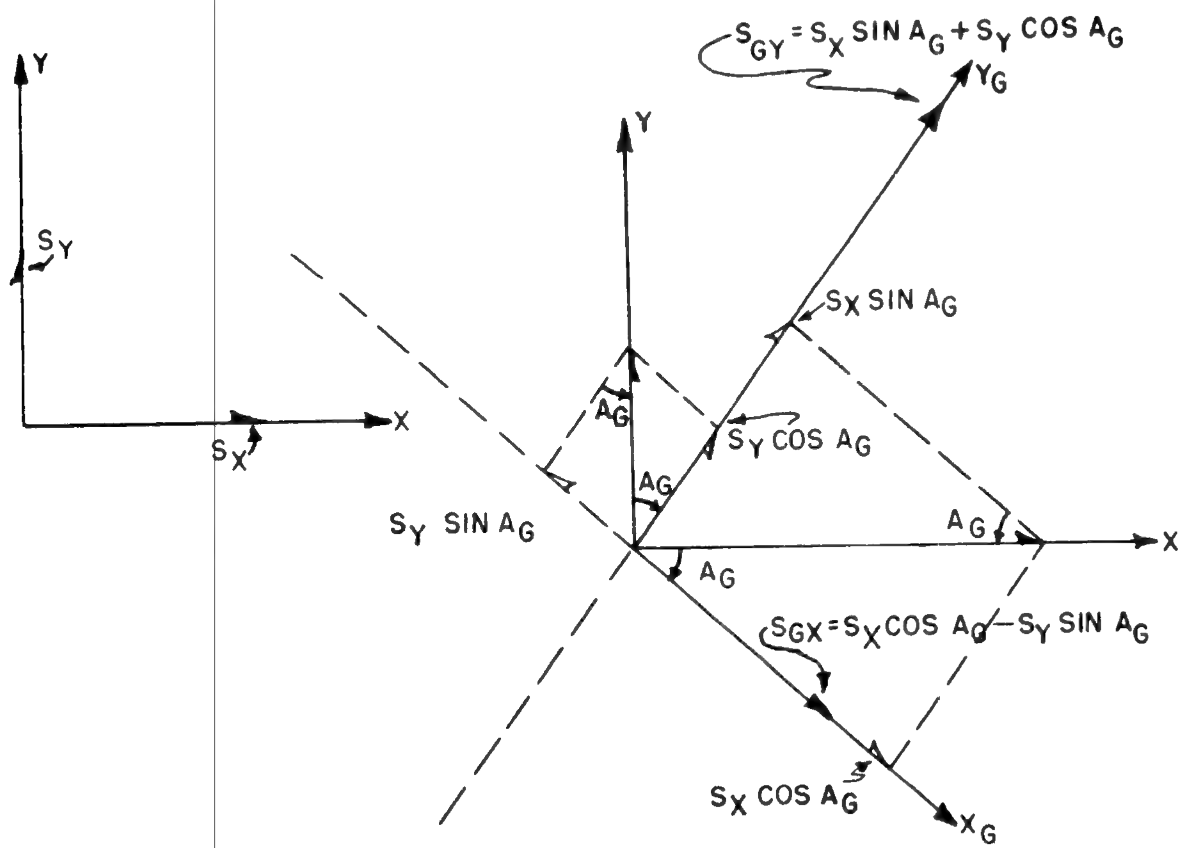


Figure 24. Conversion of steering errors from earth-to-gyro coordinate axes.

and

$$S_{GY} = S_X \sin A_G + S_Y \cos A_G. \tag{61}$$

The vector $S_Y \sin A_G$ lies in a direction opposite to $S_X \cos A_G$ and must be added vectorially (subtracted algebraically) from the term $S_X \cos A_G$. Therefore, analogs of opposing polarity are used. The inputs to the DC amplifiers (78A10) are reversed in sign from those shown in equations (60) and (61). Remember that sign reversal occurs in the DC amplifiers and produces the results indicated in the formulas.

49. PLANES AND AXIS OF REFERENCE

Planes and Axis of Reference (TM 9-5000-26, p 18) shows the horizontal plane, the gyro reference plane, and the missile velocity slant plane. The horizontal plane contains the gyro reference (Y_G) and gyro spin (X_G) axes. Perpendicular to the intersection of the X_G and Y_G axes is the gyro vertical axis, H_G. The H_G axis is in the gyro reference plane. The missile velocity axis represents the direction of motion of the missile and is in the missile velocity slant plane. The intersection of the missile velocity slant plane and the gyro reference plane is known as L_i. The climb axis is in the gyro reference plane and is perpendicular to and intersects L_i at the origin. The turn axis is in the missile velocity slant plane and is perpendicular to and intersects the missile velocity axis at the origin. The climb angle, CA, is measured between the horizontal and missile velocity slant planes. From geometry, the angle between the H_G axis and the missile climb axis is also equal to CA. The missile turn angle, TA, is the angle between L_i and the missile velocity axis measured in the missile velocity slant plane. Again by geometry, the angle between X_G and the missile turn axis is equal to TA.

50. CONVERSION FROM GYRO TO MISSILE COORDINATES (figs 25 and 26)

Converting from gyro to missile axes is only slightly more complicated than converting from earth to gyro coordinates. Not only is the missile coordinate system rotated with respect to the gyro coordinate system, but it is also tilted. The angle of rotation is the turn angle, TA, and the angle of tilt is the climb angle, CA. The first consideration is the components of steering error S_{GY} and S_H, which are contained in the gyro reference plane. These steering errors are illustrated in figure 25. The axes in the gyro reference plane are L_i and the climb axis. The quantities S_H and S_{GY} are converted into components indicated in figure 25 as S_C and S_i. The process for obtaining S_C and S_i is similar to that for obtaining S_{GX} and S_{GY} in the conversion from earth to gyro coordinates. Vectors S_{GY} and S_H are projected onto the missile climb axes and L_i. These projections produce four components: two along the missile climb axis and two along L_i. Those components derived from S_{GY} are

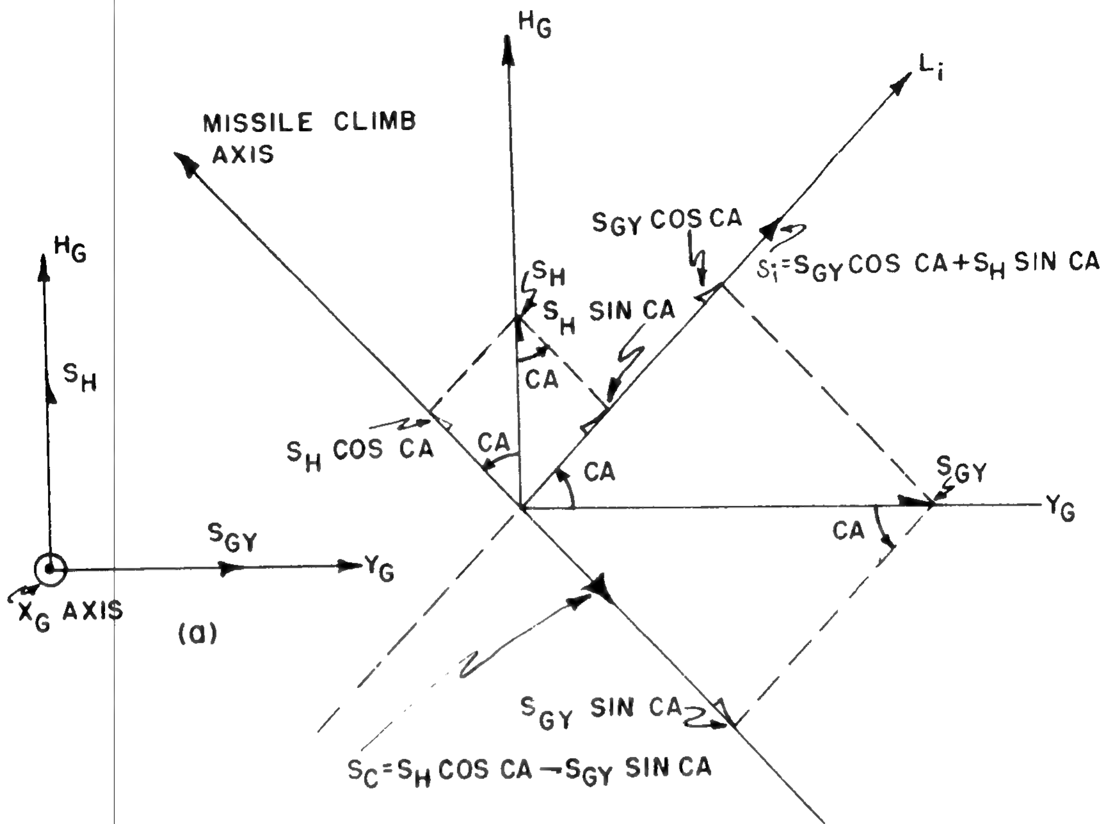


Figure 25. Coordinate system for determining steering errors in gyro reference plane.

S_{GY} cos CA and S_{GY} sin CA; those derived from S_H are S_H cos CA and S_H sin CA. S_{GY} cos CA and S_H sin CA are both positive going along L_i and are summed to obtain S_i. The vectors S_{GY} sin CA and S_H cos CA on the missile climb axis oppose each other and are summed vectorially (subtracted algebraically) to obtain S_C. Stated in equations:

$$S_i = S_{GY} \cos CA + S_H \sin CA, \tag{62}$$

and

$$S_C = S_H \cos CA - S_{GY} \sin CA. \tag{63}$$

The next consideration is the components of steering error in the missile velocity slant plane (fig 26). Vectors representing S_{GX} and S_i are shown on the perpendicular axes, X_G and L_i, respectively. In figure 26, the missile velocity axis and missile turn axis have been indicated. The turn angle is observed as the angle between L_i and the missile velocity axis and also between X_G axis and the missile turn axis. As in the preceding conversion, S_i and S_{GX} are projected onto two missile axes, the missile velocity and the missile turn axes.

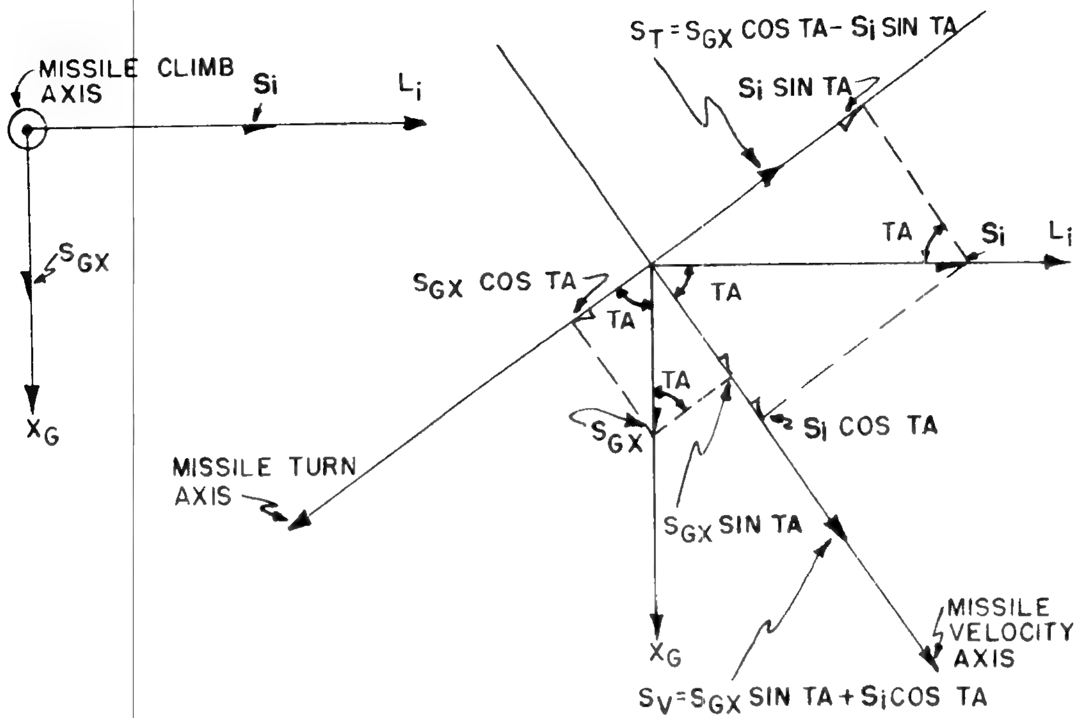


Figure 26. Steering error components in the missile velocity slant plane.

These projections produce four components. Those obtained from S_i are S_i cos TA and S_i sin TA. From S_{GX}, S_{GX} cos TA and S_{GX} sin TA are obtained. The resultant vector along the missile turn axis is called S_T, while that along the missile velocity axis is known as S_V. The vectors representing S_i sin TA and S_{GX} cos TA are summed to obtain S_T, while those representing S_i cos TA and S_{GX} sin TA are summed for S_V. Stated in equations:

$$S_T = S_{GX} \cos TA - S_i \sin TA, \tag{64}$$

and

$$S_V = S_{GX} \sin TA + S_i \cos TA. \tag{65}$$

It is already known (equation (62)) that

$$S_i = S_{GY} \cos CA + S_H \sin CA, \tag{66}$$

therefore,

$$S_T = S_{GX} \cos TA - (S_{GY} \cos CA + S_H \sin CA) \sin TA, \tag{67}$$

or

$$S_T = S_{GX} \cos TA - S_{GY} \cos CA \sin TA - S_H \sin CA \sin TA. \tag{68}$$

In like manner,

$$S_V = S_{GX} \sin TA + (S_{GY} \cos CA + S_H \sin CA) \cos TA, \quad (69)$$

or

$$S_V = S_{GX} \sin TA + S_{GY} \cos CA \cos TA + S_H \sin CA \cos TA. \quad (70)$$

In the example shown in figure 26, note that S_T is a negative component and that S_V is a positive component of steering error.

51. DETAILED OPERATION (TM 9-5000-26, p 78)

Plus and minus S_X and S_Y are applied to sine-cosine gyro azimuth potentiometers A_G-10 (78C9) and A_G-11 (78A9). Conversion to gyro coordinates takes place in these potentiometers and their outputs are sent to the $+S_{GX}$ and $+S_{GY}$ amplifiers, where they are summed to produce voltage analogs representing $+S_{GX}$ and $+S_{GY}$. The input and feedback resistors of these amplifiers are 1 megohm each. Resistors of this size prevent loading the preceding A_G potentiometers. The outputs of the positive amplifiers are directed to $-S_{GX}$ and $-S_{GY}$ amplifiers, respectively. These amplifiers only reverse polarity. The outputs of the amplifiers, representing plus and minus S_{GX} and S_{GY}, are sent to sine-cosine potentiometers positioned by the climb angle and turn angle servos. In these potentiometers, conversion to the missile climb and turn axes takes place. The outputs directed to the S_C network (78B14 and 78D14) represent S_C and satisfy equation (63), above. The outputs directed to the initial turn relay panel (78A14, 78C14, and 78D14) represent S_T and are sent through contacts of initial turn relay K124 (79A2) to the $-S_T$ network. These outputs satisfy equation (68), above. Additional outputs of the TA potentiometers go to the $-S_V$ input network. The operation of this circuit is discussed in paragraph 65, below. The detailed operations of the S_T and S_C amplifiers are discussed in paragraphs 55 and 56, respectively.

52. ILLUSTRATIVE PROBLEMS

a. Conversion from earth to gyro coordinates. Given the following data for inputs to the sine-cosine potentiometers, A_G-10 and A_G-11:

$$S_X = +300 \text{ yd/sec},$$

$$S_Y = +200 \text{ yd/sec},$$

$$A_G = 30°.$$

The results of converting S_X and S_Y into their components along the gyro axes are:

$$S_X \sin 30° = 300 \times 0.5 = +150 \text{ yd/sec},$$

$$S_X \cos 30° = 300 \times 0.866 = +259.8 \text{ yd/sec},$$

$$S_Y \sin 30° = 200 \times 0.5 = +100 \text{ yd/sec},$$

$$S_Y \cos 30° = 200 \times 0.866 = +173.2 \text{ yd/sec}.$$

The following equations are from paragraph 48.

$$S_{GX} = S_X \cos A_G - S_Y \sin A_G,$$

$$S_{GY} = S_Y \cos A_G + S_X \sin A_G.$$

Substituting the actual values,

$$S_{GX} = 259.8 - 100 = 159.8 \text{ yd/sec},$$

$$S_{GY} = 173.2 + 150 = 323.2 \text{ yd/sec}.$$

For this problem, S_H was not considered because $S_{GH} = S_H$.

To determine the voltage outputs of the $+S_{GX}$ and $+S_{GY}$ amplifiers, the scale factor of 25 mv/yd/sec is used. These outputs are:

$$S_{GX} = 159.8 \times \frac{25}{1,000} = 3.995 \text{ volts},$$

$$S_{GY} = 323.2 \times \frac{25}{1,000} = 8.08 \text{ volts}.$$

b. Conversion from gyro to missile coordinates. Given the following data:

$$S_{GX} = +100 \text{ yd/sec},$$

$$S_{GY} = +200 \text{ yd/sec},$$

$$S_H = +100 \text{ yd/sec},$$

$$CA = 45°, \text{ and}$$

$$TA = 30°.$$

Solve for S_V, S_T, and S_C. From equation (70):

$$S_V = S_{GX} \sin TA + S_{GY} \cos CA \cos TA + S_H \sin CA \cos TA.$$

Substituting,

$$S_V = +100 \times 0.5 + 200 \times 0.707 \times 0.866 + 100 \times 0.707 \times 0.866,$$

$$S_V = +50 + 122.45 + 61.23 = 233.68 \text{ yd/sec}.$$

Using the scale factor of 25 mv/yd/sec, the input to the $-S_V$ amplifier will be +5.84 volts.

Solving for S_T, from equation (68):

$$S_T = S_{GX} \cos TA - S_{GY} \cos CA \sin TA - S_H \sin CA \sin TA.$$

Substituting,

$$S_T = 100 \times 0.866 - 200 \times 0.707 \times 0.5 - 100 \times 0.707 \times 0.5,$$

or

$$S_T = 86.6 - 70.7 - 35.4 = -19.5 \text{ yd/sec}.$$

With the scale factor of 25 mv/yd/sec, the input to the $-S_T$ amplifier will be -0.49 volt. Finally, the solution for S_C uses the formula $S_C = S_H \cos CA - S_{GY} \sin CA$.

Substituting,

$$S_C = +100 \times 0.707 - 200 \times 0.707,$$

$$S_C = +70.7 - 141.4 = -70.7 \text{ yd/sec}.$$

At 25 mv/yd/sec, the input to the S_C amplifier is -1.77 volts.

Section X. FIN ORDER SOLVER

53. GENERAL

The fin order solver determines the steering orders to be sent to the missile to cause it to change direction and intercept the target. In computing the required orders, the fin order solver calculates the components of the orders required by each fin pair. This is necessary because the P-fin and Y-fin planes are located 45° from the missile velocity slant plane and the gyro reference plane. If a turn to the right or left is desired, the order must be applied in part to both fin pairs. There is no way of regulating the speed of the missile directly, so transverse accelerations must be applied to the missile to change its heading.

These accelerations cause the velocity components along the climb and turn axes to change. The inputs to the fin order solver are the steering errors along the climb and turn axes, S_C and S_T. The outputs, G_Y and G_P, are voltage analogs of acceleration and are sent to the missile-tracking radar, where they are combined to cause proper orders to be sent to the missile. The input scale factor is 40 mv/yd/sec and the output scale factor is about 20 volts per g. Before actual steering errors are used by the fin order solver, other inputs are sent to the section. These inputs are the 7g dive order and skirting turn orders (if required). The 7g dive order is explained in paragraphs 123 through 125 of this text. Skirting turn orders are explained in TM 9-5000-14.

54. MATHEMATICAL ANALYSIS

a. Coordinate conversion. The velocity steering errors, S_T and S_C, are in the missile velocity slant plane and gyro reference plane, respectively. Before they can be used to determine the orders to be applied to the missile fins, they must be converted into components of steering errors perpendicular to the fin planes (fig 27). Figure 27(1) is a rear view of the missile and shows the missile climb and turn axes and the positions of the P- and Y-fin pairs. Figure 27(2) shows the steering errors, S_T and S_C, drawn as vectors along the missile turn and climb axes. Figure 27(3) shows the conversion of S_T and S_C to S_{PF} and S_{YF}. This conversion is done in the same manner as the conversions from earth to gyro coordinates and from gyro to missile coordinates. Projections are dropped from S_T and S_C to axes perpendicular to the Y-fin and P-fin planes. The steering error in the Y-direction, S_{YF}, lies along an axis perpendicular to the Y-fins. This orientation is necessary, since S_{YF} must lie in the axis that is in the direction in which the Y-fins can turn the nose of the missile. The Y-fins cause the missile to climb to the right or dive to the left. Similarly, the steering error in the P-direction, S_{PF}, must lie along an axis perpendicular to the P-fins. The P-fins cause the missile to climb to the left or dive to the right. Stated mathematically,

$$S_{YF} = S_C \sin 45° + S_T \cos 45°, \tag{71}$$

$$S_{PF} = S_C \cos 45° - S_T \sin 45°. \tag{72}$$

The sine and cosine of 45° are both equal to 0.707. Therefore,

$$S_{YF} = 0.707\,(S_C + S_T), \tag{73}$$

$$S_{PF} = 0.707\,(S_C - S_T). \tag{74}$$

The computer must now determine the steering orders to be sent to the missile, using S_{YF} and S_{PF} as known quantities. The steering errors have dimensions

of velocity, while the steering orders are in terms of acceleration. The steering orders must cause an average change in missile velocity which will just cancel the steering error in the remaining time to intercept.

b. The velocity equation. Consider the formula

$$V = \frac{1}{2}at, \tag{75}$$

where a represents constant acceleration, t represents the time during which the object is accelerating, and V is the average velocity over the entire time interval from zero to t seconds.

c. Acceleration orders. To calculate the acceleration required by the missile, the steering error perpendicular to one of the fin pairs is substituted in the above formula:

$$S_{PF} = \frac{1}{2}at. \tag{76}$$

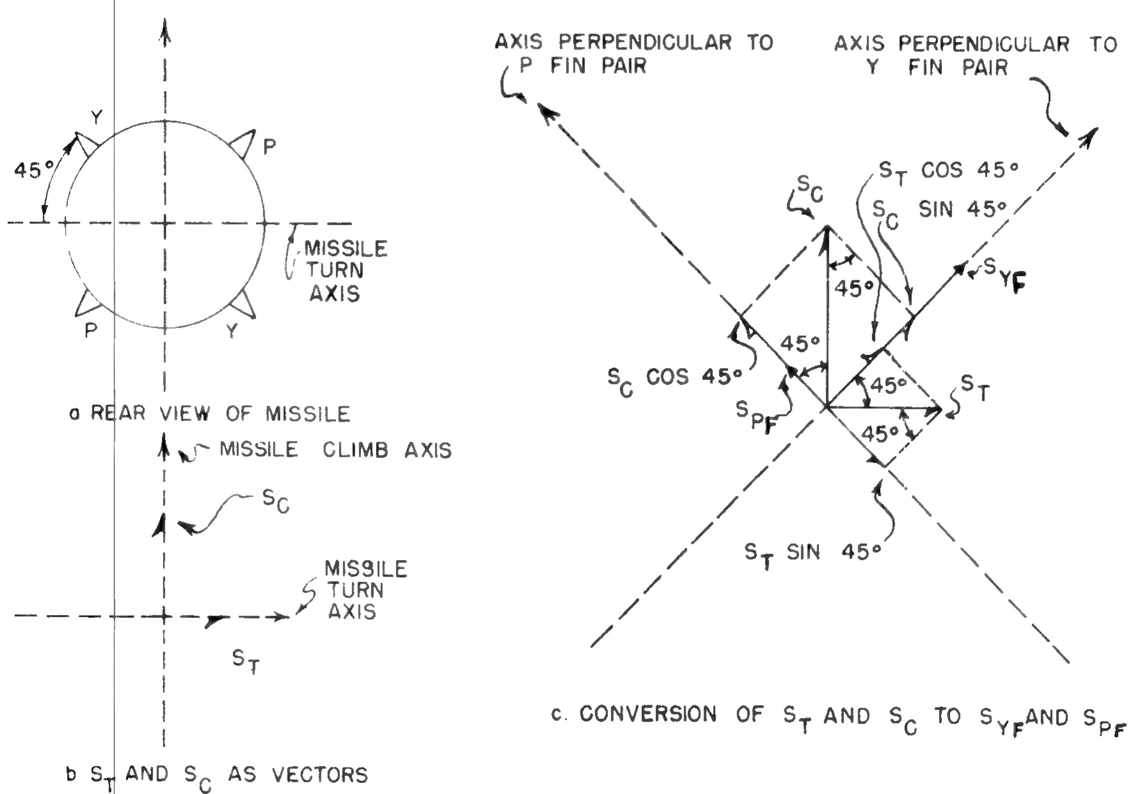


Figure 27. Conversion of velocity steering errors.

Solving this equation for a, the acceleration order which must be applied to the missile P-fin pair is:

$$a = \frac{2S_{PF}}{t}. \tag{77}$$

The computer sends orders to the missile in terms of g's. One g is equal to approximately 10.7 yards per second per second. Therefore, the number of g's acceleration to be applied is:

$$a \text{ (in g's)} = \frac{2S_{PF}}{10.7t}. \tag{78}$$

The orders sent to the Y-fin pair are called G_Y, those sent to the P-fin pair are called G_P. The orders determined above are the accelerations that must be applied to the missile to cancel the steering error in the remaining time to intercept. It is necessary, however, to apply slightly more than the minimum order required to reduce the steering error to zero before intercept occurs. The strength of the order is increased by one and one-half. Then the equation for G_P is:

$$G_P = \frac{2S_{PF}}{10.7t} \times \frac{3}{2} = \frac{3S_{PF}}{10.7t}, \tag{79}$$

but

$$S_{PF} = 0.707\ (S_C - S_T) \text{ (equation (74))},$$

therefore,

$$G_P = \frac{3 \times 0.707\ (S_C - S_T)}{10.7t} = \frac{0.198\ (S_C - S_T)}{t}. \tag{80}$$

Similarly,

$$G_Y = \frac{2S_{YF}}{10.7t} \times \frac{3}{2} = \frac{3S_{YF}}{10.7t}, \tag{81}$$

but

$$S_{YF} = 0.707\ (S_C + S_T) \text{ (equation (73))}.$$

Therefore,

$$G_Y = \frac{3 \times 0.707\ (S_C + S_T)}{10.7t} = \frac{0.198\ (S_C + S_T)}{t}. \tag{82}$$

By increasing the orders shown above by the constant factor of three-halves, the steering error is canceled in only two-thirds of the remaining time to intercept. This action insures removal of the error at considerable distance from the intercept point.

55. DETAILED ANALYSIS OF THE $-S_T$ AMPLIFIER CIRCUIT

a. Circuit analysis. See 79A2 and locate the contacts of relay K124, contained in the initial turn relay panel. These relay contacts control the inputs to the $-S_T$ amplifier input network. Before the RADAR CLEARED and ON TRAJECTORY signals, relay K124 is energized. The input to the $-S_T$ amplifier at this time is the initial turn order from the initial turn section. **The function and derivation of these inputs are described in detail in TM 9-5000-14. The inputs** that make up S_T enter on contacts 1, 3, and 5 of K124 when it deenergizes. The $-S_T$ amplifier is a conventional, 3-stage DC amplifier with a diode limiter circuit in parallel with the feedback circuit. This circuit limits the output to ±90 volts. The operation of this diode limiter is explained in detail in paragraph 88 of this text. The $-S_T$ amplifier is used primarily as a combining amplifier for the several inputs. Locate contacts 6 and 11 of K32, an OTL relay, and contacts 1, 2, and 9, and 3, 4, and 10 of K125, an IT relay. When initial turn orders are applied (before ON TRAJECTORY and RADAR CLEARED), relay K125 energizes. This performs two functions.

(1) Contacts 2 and 9 of energized relay K125 increase the gain of the $-S_T$ amplifier by placing the voltage divider consisting of R121, R122, and R123 in the feedback circuit. Contacts 6 and 11 of relay K32 (OTL) cause the junction of R122 and R123 to be grounded before ON TRAJECTORY. If ON TRAJECTORY is received before RADAR CLEARED, the contacts open, adding R123 to the voltage divider. This addition decreases the gain of the $-S_T$ amplifier after ON TRAJECTORY. When the 7g dive is initially applied, only one fin pair will respond to an initial turn command. After ON TRAJECTORY, however, both fin pairs will respond to the initial turn commands. Since both fin pairs now respond to the initial turn order, increased missile response would result from the same initial turn order. Provision must be made for this added response. The action of K32 in decreasing the amplifier gain, as described above, provides the required compensation.

(2) Contacts 4 and 10 of K125 place the time potentiometer T_C-11A in the output circuit of the $-S_T$ amplifier when initial turn orders are being transmitted. This causes the output to be multiplied by time to intercept. This multiplication gives the initial turn data, representing angular mils, a time dimension. Another time potentiometer in the feedback circuits of the G_Y and G_P amplifiers causes division by time when G_Y and G_P are generated. Potentiometer T_C-11A thus nullifies the effect of the division by time when steering orders are developed from initial turn data.

b. Gimbal limit. Consider next the plus and minus GIM L relay contacts (75A6). The coils of these relays may be found on 109B10 and 109C10. The relays, K126 and K127, are energized by cam-operated microswitches on the TA servo. The roll-amount gyro causes a definite limit to be placed upon the missile turn angle. If the total turn of the missile amounts to 90° or more, control of the missile is lost because of gimbal lock. Gimbal lock will occur with a turn of 90° because the gyro spin axis becomes alined with the gyro outer gimbal axis. The cam-operated microswitches will energize either K126 or K127 when the TA servo shaft is displaced to ±70°. The missile angle of attack may be as much as 15°. The angle of attack is the angle between the missile longitudinal axis and the missile velocity axis. An angle of attack is present when the missile is skidding through the air. The sum of these (70° plus 15°) equals 85°. The extra 5° is allowed as a safety precaution. When one switch or the other is operated, a voltage representing positive or negative time to intercept replaces the output of the $-S_T$ amplifier. This time-to-intercept voltage will result in a turn order of approximately 2.45g's being applied in the turn direction. This ±t-voltage will be removed as soon as the turn angle servo is positioned at an angle less than 70°. Besides replacing the output of the $-S_T$ amplifier, relays K126 and K127 cause a light on the tactical control panel to glow and an output to be sent to the event recorder when they are energized.

c. $-S_T$ output circuitry. The output of the $-S_T$ amplifier is sent to four places.

(1) Terminal 3 of the $+S_T$ amplifier input network. Simple sign reversal occurs to produce the opposite value of S_T.

(2) Plug P1-4 of the G_Y order-shaping panel (81A9). This input is discussed in paragraph 115 of this text.

(3) Terminal 3 of the G_Y amplifier input network (81A11). This input is used in the actual determination of the steering order to be sent to the Y-fin pair.

(4) Contact 5 of relay K125 of the initial turn relay panel (81A10). This input is used only when initial turn data are being applied through the $-S_T$ amplifier.

d. $+S_T$ output circuitry. The output of the $+S_T$ amplifier is sent to three places.

(1) Plug P1-15 of the Gp order-shaping panel (81C9). This input is discussed in paragraph 115 of this text.

(2) Terminal 3 of the G_P amplifier input network (81D11). This input is used in the actual determination of the steering order to be sent to the P-fin pair.

(3) Contact 7 of relay K125 of the initial turn relay panel (81D10). This input is used only when initial turn data are being applied through the $-S_T$ amplifier.

56. DETAILED ANALYSIS OF THE $-S_C$ AMPLIFIER CIRCUIT

a. Circuit operation. Refer to 79D3 of 2y and locate the $-S_C$ amplifier input network. The inputs to the circuit are $+S_H$ cos CA at terminal 3 and $-S_{GY}$ $-S_{GY}$ sin CA at terminal 4. These inputs are summed to produce a voltage proportional to the steering error along the missile climb axis. The $-S_C$ amplifier is a conventional, 3-stage DC summing amplifier. Its output is sent to two places, contact 7 of relav K32 in the steering switching relay panel and the OT amplifier (79D5 and 79D6). The steering switching relay panel receives two inputs, voltages representing +t and $-S_C$. The +t-voltage is used first in the sequence of events and causes the 7g dive order to be generated by the fin order solver. Its operation is discussed in paragraphs 122 through 125 of this text. When ON TRAJECTORY is detected, relay K32 is energized, removing the +t-input and applying the climb steering error, $-S_C$.

b. $-S_C$ output circuitry. These outputs, $-S_C$ or +t, are sent to four places.

(1) Plug P1-8 of the G_Y order-shaping panel (81A9). This input is discussed in paragraph 115 of this text.

(2) Terminal 4 of the G_Y amplifier input network (81A11). This input is used in the actual determination of the steering order to be sent to the Y-fin pair.

(3) Plug Pi-7 of the G_P order-shaping panel (81C10). This input is discussed in paragraph 115 of this text.

(4) Terminal 4 of the G_P amplifier input network (81D11). This input is used in the actual determination of the steering order to be sent to the P-fin pair.

57. DETAILED FUNCTIONAL ANALYSIS OF THE G_Y AND G_P AMPLIFIER CIRCUITS (TM 9-5000-26, p 81)

The G_Y and G_P amplifier circuits have three possible inputs.

a. G_Y inputs before ON TRAJECTORY. Before ON TRAJECTORY the inputs to the G_Y amplifier are initial turn orders, if required, and a voltage representing time to intercept, which causes the 7g dive. This voltage representing t is applied to terminal 4 of the G_Y input network. At the scale factor of 1 volt per second, this potential may vary from zero to +100 volts. The inputs at terminals 3 and 5 are the initial turn orders from the $-S_T$ amplifier. The input and feedback resistors are all 1 megohm. Since $-S_T$ enters at two points, the output caused by this input is twice as effective as it would be if only one input were present.

(1) Consider the input at terminal 4 representing time to intercept. This input produces an output from the G_Y amplifier, which always represents 5g's. The output scale factor is 20 volts per g. Therefore, the output must be -100 volts. This can be seen by considering the time-to-intercept potentiometer in the feedback loop of the G_Y amplifier. The extent of the travel of the brush arm of this potentiometer, T_C-13A, is from zero seconds at ground to 100 seconds at the top. Suppose the input is a voltage representing t seconds. The brush arm will also be positioned at t seconds. Consider the following formula:

$$-E_{out} = E_{in} \times \frac{R_B}{R_{in}} \times \frac{R_1 + R_2}{R_2}.$$

In this formula, E_{in} is t, R_B and R_{in} are both 1 megohm, R1 + R2 is 100 seconds, and R2 is t seconds. Therefore,

$$-E_{out} = t \times \frac{1}{1} \times \frac{100}{t} = 100 \text{ volts}.$$

At 20 volts per g, the output is the desired amount, -5g's. This voltage will cause the missile to dive to the left.

(2) The other inputs to the G_Y amplifier represent $-S_T$ or, in this case, the required skirting errors for a successful initial turn. Suppose a turn to the right is required. The voltage entering on terminals 3 and 5 will be negative. Sign reversal will occur in the G_Y amplifier, causing the output to be positive. The positive voltage causes a turn to the right, accompanied by a decrease of the 5g dive output explained before.

b. G_P inputs before ON TRAJECTORY. The inputs to the G_P amplifier are similar to the inputs to the G_Y amplifier. The positive voltage representing time to intercept enters on terminal 4 and produces -100 volts (-5g's) on the output. This voltage causes a dive to the right; -100 volts (-5g's) from the G_Y

amplifier produces a dive to the left. The turn components will cancel and the two -5g dive commands produce a total dive effect of 7g's. Consider that a skirting turn to the right is desired. The input voltages to terminals 3 and 5 represent $+S_T$ or the skirting turn angle voltage. For a turn to the right this voltage must be positive. Sign reversal occurs in the G_P amplifier. Therefore, the output should be a negative voltage. It was seen above that the output is already -100 volts in producing the 7g dive order. The G_Y and G_P limiter prevents the output of the G_Y or G_P amplifiers from exceeding ±100 volts. Therefore, the input representing the skirting turn order does not affect the output. The skirting turn orders affect only one of the two amplifiers, G_Y or G_P, when the 7g dive order is applied. When the dive order is removed, the skirting turn orders are applied to both fin pairs.

c. Output circuits. The outputs of the G_Y and G_P amplifiers may be considered similarly. Consider the output of the G_Y amplifier at P325. This output goes to contact 5 of relay K24, a steering relay which is energized about 4 seconds after MISSILE AWAY is detected. Contacts 5 and 11 of K24 are closed at this time providing electrical connection to contact 2 of relay K31, an ACTION relay which is energized at all times during an engagement. Contacts 9 and 2 of K31, therefore, are closed and provide a current path through the battery control trailer junction box and the radar range and receiver cabinet to the yaw oscillator in the missile-tracking radar console. A similar path may be traced from the output of the G_P amplifier to the pitch oscillator.

d. Order limiting circuit. The plus and minus order limiting circuit is shown at 81B10. This circuit limits the output of the G_Y and G_P amplifiers to specified values as a function of altitude. The missile tends to develop instabilities if maximum possible orders are applied to the fins at high altitudes. Consequently, above 30,000 feet the maximum possible order is decreased by action of the plus and minus order limiting circuit. The operation of this circuit is discussed in paragraphs 94 through 106 of this text.

e. Order meters. At the output of the G_Y and G_P amplifiers note the G_Y and G_P order meter. This meter is located on the tactical control panel of the battery control console (fig 28). The meter indicates, in g's, the magnitude of the outputs of the G_Y and G_P amplifiers. Two red needles (indicated in black printing) are used, one for G_Y and the other for G_P. The missile climb and turn axes are also shown. The climb axis is a vertical white line, while the turn axis is a white arc. By careful inspection of the meter, the amount and direction of climb or turn can be determined from the intersection of the two needles. For example, assume that only a climb order was transmitted; the intersection of the two needles would be on the upper portion of the climb axis.

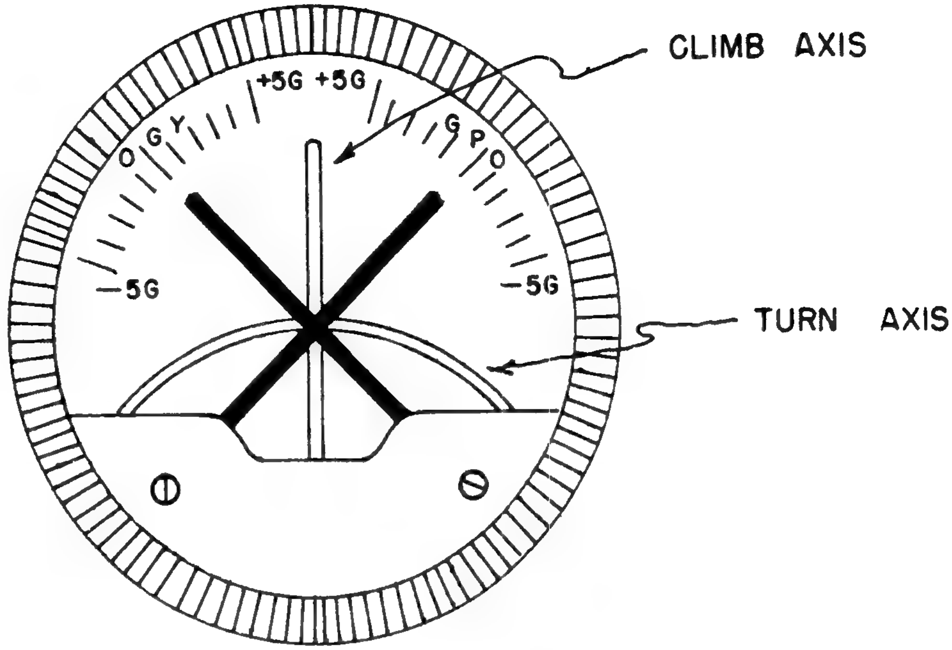


Figure 28. Fin orders meter, showing climb and turn axes.

f. Event recorder. The G_Y and G_P orders are also sent to the event recorder. The operation of this component is discussed in TM 9-5000-16.

g. Inputs after ON TRAJECTORY. After ON TRAJECTORY, the steering error along the missile climb axis, S_C, replaces the +t-voltage, which produced the 7g dive, as an input to the G_Y and G_P amplifiers. After both ON TRAJECTORY and RADAR CLEARED, the steering error along the turn axis (S_T) replaces the initial turn order (if any). At this time, relay K125 deenergizes, placing ground at terminal 5 of the G_Y and G_P amplifier input networks.

58. ILLUSTRATIVE PROBLEM

Assume the following components of steering error given:

$$S_C = +300 \text{ yards per second,}$$

$$S_T = +200 \text{ yards per second,}$$

$$t = 20 \text{ seconds.}$$

The following equations are known:

$$G_Y = \frac{0.198\ (S_C + S_T)}{t},$$

$$G_P = \frac{0.198\ (S_C - S_T)}{t}.$$

Therefore,

$$G_Y = \frac{0.198\ (300 + 200)}{20} = \frac{0.198 \times 500}{20},$$

$$G_Y = 4.95g's.$$

And

$$G_P = \frac{0.198\ (300 - 200)}{20} = \frac{0.198 \times 100}{20},$$

$$G_P = 0.99g.$$

The above quantities shown as solutions for G_Y and G_P are in terms of g's. Using the same terms, it is possible to solve for G_Y and G_P using voltages. Refer to the inputs of the $-S_T$ and $-S_C$ amplifiers (79A3 and 79D3). The input resistors are all 0.5 megohm and the feedback resistors are 0.8 megohm. This provides a multiplication factor of 8/5. The inputs to the $-S_T$ and $-S_C$ amplifiers are: 200 times 0.025, or 5 volts; and 300 times 0.025, or 7.5 volts, respectively. Remember that the input scale factor is 25 mv/yd/sec. The outputs of the $-S_T$ and $-S_C$ amplifiers are:

$$-S_T = 5 \times \frac{8}{5} = 8 \text{ volts},$$

$$-S_C = 7.5 \times \frac{8}{5} = 12 \text{ volts}.$$

The outputs from the G_Y and G_P amplifiers may be determined from the following formula:

$$-E_{out} = E_{in} \times \frac{R_B}{R_{in}} \times \frac{R_1 + R_2}{R_2}.$$

The term E_{in} consists of the combinations of S_C and S_T. The term $\frac{R_1 + R_2}{R_2}$ is the ratio of time to intercept (20 seconds) to total time (100 seconds). Substituting the known data in the equation given above,

$$-G_Y = (-S_T - S_C) \times \frac{1}{1} \times \frac{100}{20},$$

$$-G_Y = (-8 - 12) \times 5 = -100 \text{ volts},$$

$$+G_Y = +100 \text{ volts} = 5\text{g's}.$$

In like manner,

$$-G_P = (+S_T - S_C) \times \frac{1}{1} \times \frac{100}{20},$$

$$-G_P = (+8 - 12) \times 5 = -20 \text{ volts},$$

$$+G_P = +20 \text{ volts} = 1\text{g}.$$

From the strict mathematical analysis of the problem, the results for G_Y and G_P were found to be as follows:

$$G_Y = 4.95 \text{ g's}, \qquad G_P = 0.99\text{g}.$$

The actual voltages produced are slightly larger than would be indicated from mathematics alone. This is satisfactory, however, since the increase is not enough to cause overshoot.

59. THE FIN ORDER SOLVER AS A SERVO ELEMENT

The entire Nike system may be considered a servo system with the fin order solver as a portion. In review, think of a basic servo consisting of a reference input, comparator, controller, controlled variable, and feedback. This basic servo receives the input, generates an actuating error, and produces a controlled variable by which useful work is done. A part of the controlled variable is fed back to be balanced against the reference input. When the reference input and the feedback function are equal, the actuating error will be zero and the controlled variable will be correct. The controller elements are sometimes called gain devices. The fin order solver is part of the controller of the Nike system servo loop.

60. THE NIKE SYSTEM AS A SERVO

Figure 29 shows the Nike system depicted as a servo. The reference input consists of two elements: present target position X_T, Y_T, and H_T; and target velocity $\dot{X}_T$, $\dot{Y}_T$, and $\dot{H}_T$. The comparator consists of two computer components, the closing speed solver and the steering error solver. The feedback function consists of voltages which represent present missile position X_M, Y_M,

and H_M. Missile and target position and missile and target velocities are compared to produce an actuating error, S_X, S_Y, and S_H. However, actual and ideal closing velocities are compared to produce the steering errors (section VII). The controller or gain elements consist of several components. The steering error converter converts the steering errors in earth coordinates to steering errors along the missile climb and turn axes, S_C and S_T. The fin order solver produces accelerations that are transmitted to the missile by the missile-tracking radar. The electronics and hydraulics of the missile move the missile fins to produce the desired change in missile position to place the missile on the correct trajectory. Missile position is the controlled variable and constitutes the feedback to the missile-tracking radar. The missile-tracking radar is the first of three feedback elements and produces missile position in the form of spherical coordinates. The missile coordinate converter produces missile present position in rectangular coordinates and the missile differentiators give voltages which represent the rate of change of $\dot{X}_M$, $\dot{Y}_M$, and $\dot{H}_M$. Both X_M, Y_M, and H_M, and $\dot{X}_M$, $\dot{Y}_M$, and $\dot{H}_M$ are feedback functions. The desired change of missile position is seen at the comparator, canceling the actuating error.

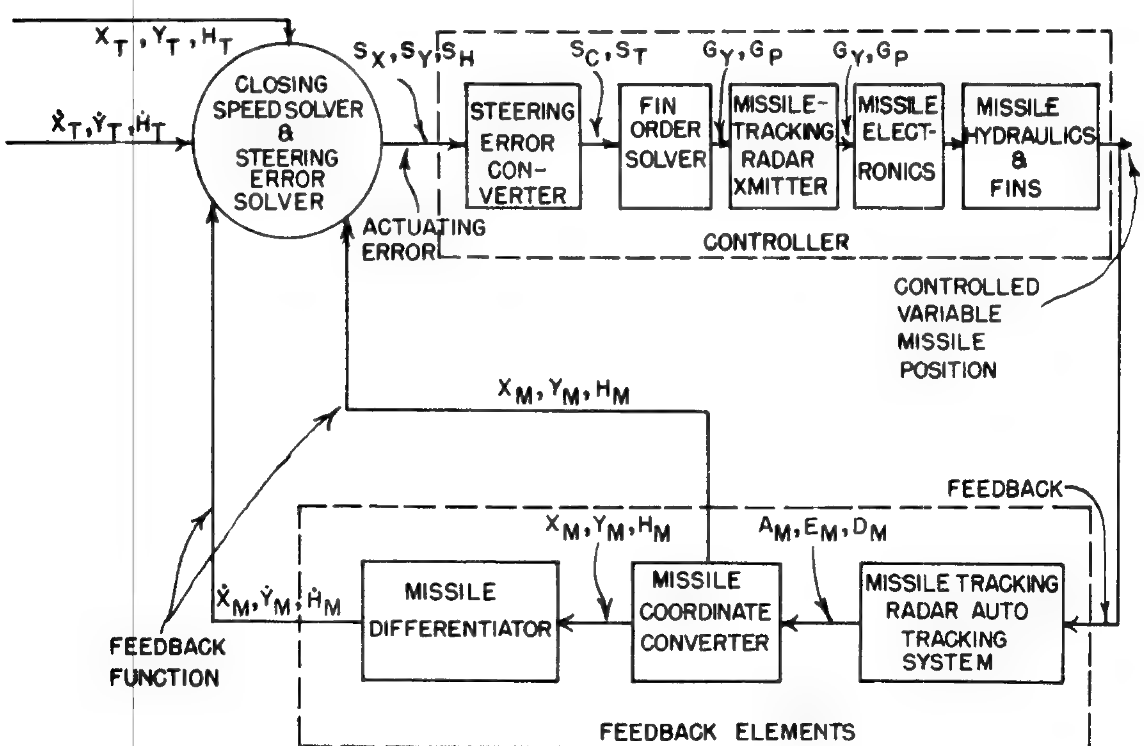


Figure 29. The Nike system as a servo system.

Section XI. TIME-TO-INTERCEPT SERVO

61. GENERAL

The time-to-intercept servo is a servomechanism which continuously solves for remaining time to intercept during the computer steering phase. There are two reference inputs to this servomechanism: actual closing velocity, and position difference, X, Y, and H. The output of the servomechanism (controlled variable) is the position of a shaft, which is proportional to the remaining time to intercept. The comparator consists of the steering error solver and the steering error converter. The servomecnanism is composed of the following major functional units and components:

Steering error solver.
Steering error converter.
Closing speed solver.
t_s input network.
t-amplifier.
Plus and minus t-amplifiers.
Second-per-second bias network.
Low-power servoamplifier.
Modulator.
Servomotor generator.
Output shaft and gearing, cams, and microswitches.
Potentiometers.

During the prelaunch configuration, the t-amplifier, low-power servoamplifier, modulator, motor-tachometer, output shaft, gearing, cams, microswitches, and potentiometers are part of the time-of-flight predictor. The functional components of the time-to-intercept servo are physically distributed about the computer amplifier and servo cabinets. The outputs of the time-to-intercept servo are of two types. One type is the position of the shaft which is analogous to time. This output is designated by the symbol t. The other type is a voltage and is designated on the schematic diagrams of TM 9-5000-26 by the symbols +t or -t. The voltage scale factor is 1 volt per second. The position of the output shaft, t, determines the position of the brush arm on each of the 21 potentiometers in the time-to-intercept servo assembly. Some of these potentiometers are coarse potentiometers and others are fine potentiometers. In each case, the shaft is positioned so that the voltage tapped off any coarse potentiometer is given by the following expression:

$$E_{tapped} = \frac{t}{t_{max}} \times E_{applied},$$

and, since t_{max} is equal to 100 seconds:

$$E_{tapped} = 0.01 \times E_{applied} \times t.$$

For fine potentiometers t_{max} is equal to 25 seconds:

$$E_{tapped} = 0.04 \times E_{applied} \times t.$$

62. MATHEMATICAL ANALYSIS

Time remaining to intercept is determined mathematically by using the well-known relationship: distance is equal to rate multiplied by time. In the problem solved by the Nike I computer, the distance is the missile-to-target distance (position difference) and the rate is the actual closing velocity. Thus, the equation for time to intercept is:

$$\text{time to intercept} = \frac{\text{position difference}}{\text{actual closing velocity}}.$$

63. ONE-DIMENSIONAL PROBLEM

As an aid in understanding the reasoning involved in determining time to intercept, consider the following problem, shown in figure 30, which is a special case:

Problem: Determine the remaining time to intercept and the location of the intercept point.

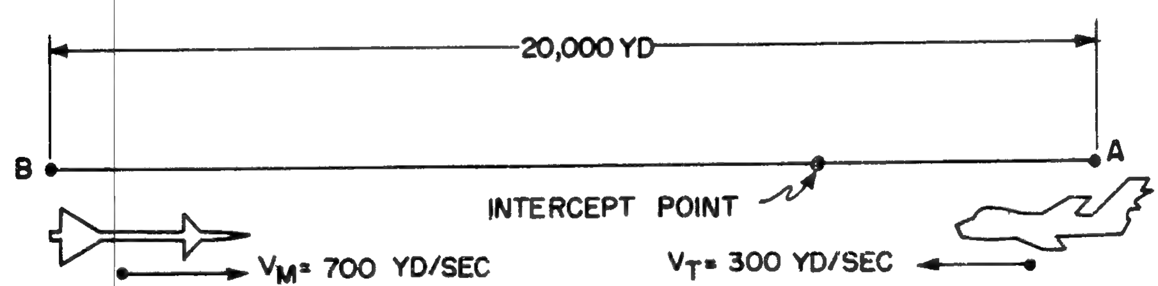


Figure 30. One-dimensional time-to-intercept problem.

Given: Target is at point A, missile is at point B.

The distance from A to B is 20,000 yards.

Target velocity is 300 yards per second, directed from A to B.

Missile velocity is 700 yards per second, directed from B to A.

Solution: The actual closing velocity is 300 + 700 = 1,000 yd/sec.

The position difference is 20,000 yards, since that is the distance between points A and B. By substitution in the equation:

$$\text{time to intercept} = \frac{\text{position difference}}{\text{actual closing velocity}},$$

$$t = \frac{20{,}000}{1{,}000} \text{ or, } t = 20 \text{ seconds.}$$

The target will travel 300 x 20 = 6,000 yards from A to the intercept point. Therefore, the intercept point is 6,000 yards from point A. The missile will travel 700 x 20 or 14,000 yards from point B to the intercept point. Therefore, the intercept point is 14,000 yards from point B. Assume that the output shaft of the time-to-intercept servo indicates 19 seconds. The target will travel 300 x 19 = 5,700 yards from A, and the missile will travel 700 x 19 = 13,300 yards from point B. The position difference, however, is 20,000 yards; therefore, the target and the missile are still 1,000 yards apart when time becomes zero. Obviously, time remaining to intercept is incorrect. In this special case the missile is flying the correct course, so direction of flight cannot be changed, but time must be changed. In the time servo loop, the incorrect time of 19 seconds divides the position difference of 20,000 yards. The ideal closing velocity is $\frac{20{,}000}{19} = 1{,}052.6$ yd/sec. In the steering error solver the ideal closing velocity, 1,052.6 yd/sec, is compared algebraically with the actual closing velocity, 1,000 yd/sec. Steering velocity error $S_V = 52.6$ yd/sec. This velocity error causes the time servo to increase time, and as time increases, the ideal closing velocity of 1,052.6 yd/sec becomes smaller. When time is 20 seconds, the ideal closing velocity is equal to the actual closing velocity and $S_V = 0$. The missile and the target will reach the same point in space when the output of the time-to-intercept servo is equal to 20 seconds. If time is less than 20 seconds, they will be separated when time is zero. If time is greater than 20 seconds, the missile and target will overshoot and be beyond each other at time zero. The controlled variable is time to intercept. The servomechanism is actuated by an error voltage that continuously attempts to approach

a zero value. The equation for determining time to intercept,

$$t = \frac{\text{position difference along the } M_V \text{ axis (D)}}{-\text{ actual closing velocity along the } M_V \text{ axis (V)}}, \tag{83}$$

is not in a form that can be readily solved by the time-to-intercept servo. The error voltage that activates the time-to-intercept servo is S_V. The equation which the servo solves to compute time to intercept correctly is:

$$S_V = 0. \tag{84}$$

Mathematically, equation (84) is obtained by rewriting equation (83) as follows:

$$t = \frac{D}{-V}. \tag{85}$$

Rearranging terms:

$$-V = \frac{D}{t}. \tag{86}$$

By further rearrangement:

$$\frac{D}{t} + V = 0. \tag{87}$$

Since $\frac{D}{t}$ and V are components of ideal and actual closing velocity along the missile velocity axis, the expression $(\frac{D}{t} + V)$ is equal to S_V. Therefore,

$$S_V = 0. \tag{84}$$

When S_V is not zero, the solution for time to intercept is not correct and the output (t) of the time-to-intercept servo is changed until S_V does become zero.

64. SIMPLIFIED OPERATION OF TIME-TO-INTERCEPT SERVO

a. Functional operation. A simplified functional block diagram of the servomechanism that solves for the remaining time to intercept is shown in figure 31. The output quantity (controlled variable) is the remaining time to intercept, t. The two reference inputs are the rectangular earth coordinates of actual closing velocity ($\dot{X}$, $\dot{Y}$, and $\dot{H}$) and the rectangular earth coordinates

of position difference (X, Y, and H). The output, t, is fed back mechanically to the closing speed solver (feedback element). The position difference voltages are applied to the closing speed solver. In the closing speed solver, the position difference is divided by time so that the outputs of the closing speed solver are the components of ideal closing velocity along the rectangular earth axes ($\frac{X}{t}$, $\frac{Y}{t}$, and $\frac{H}{t}$). These are feedback functions of the controlled variable. Actual closing velocity and ideal closing velocity are applied to the comparator (steering error solver and steering error converter). Within the comparator, the actual and ideal closing velocities are compared. If these two quantities, always opposite in polarity, do not add up to zero, then an error voltage exists. The error voltage is converted within the comparator to an error voltage which represents the steering error along the missile velocity axis. The output of the comparator is S_V, the actuating error, which is applied as an actuating voltage to the controller. S_V is a d-c voltage. Within the controller, it is converted to an a-c driving voltage, which is amplified and applied to the servomotor, causing the position of the output shaft to change until the actuating error, S_V, is reduced to zero. The solution for remaining time to intercept is correct when S_V is zero. When S_V is positive, t increases; when S_V is negative, t decreases.

b. Feedback loops. There are three separate and distinct feedback loops within the block (fig 31) representing the controller. One of these feedback loops is generator feedback, which stabilizes the servomechanism. This type feedback loop is discussed in considerable detail during the course of instruction on the acquisition radar and is reviewed in TM 9-5000-13.

c. Gain compensation feedback. The second feedback loop in the time servo multiplies the actuating error, S_V, by time (fig 32). In the discussion of the steering error converter it was pointed out that the steering errors, S_C, S_T, and S_V, were velocity components. It has also been shown that velocity equals distance divided by time.

$$-V = \frac{D}{t}.$$

From this equation, notice that if time is small, the velocity will be large, distance remaining constant. This means, in regard to the time servo, that as time decreases the actuating error will increase in size for the same distance error. This is not desirable. To prevent this and make the time-to-intercept servo equally responsive to a given distance error, regardless of the time-to-intercept solution, S_V is multiplied by time, or:

$$\frac{D}{t} \times t = D.$$

Therefore, the time servo is responsive only to the distance error.

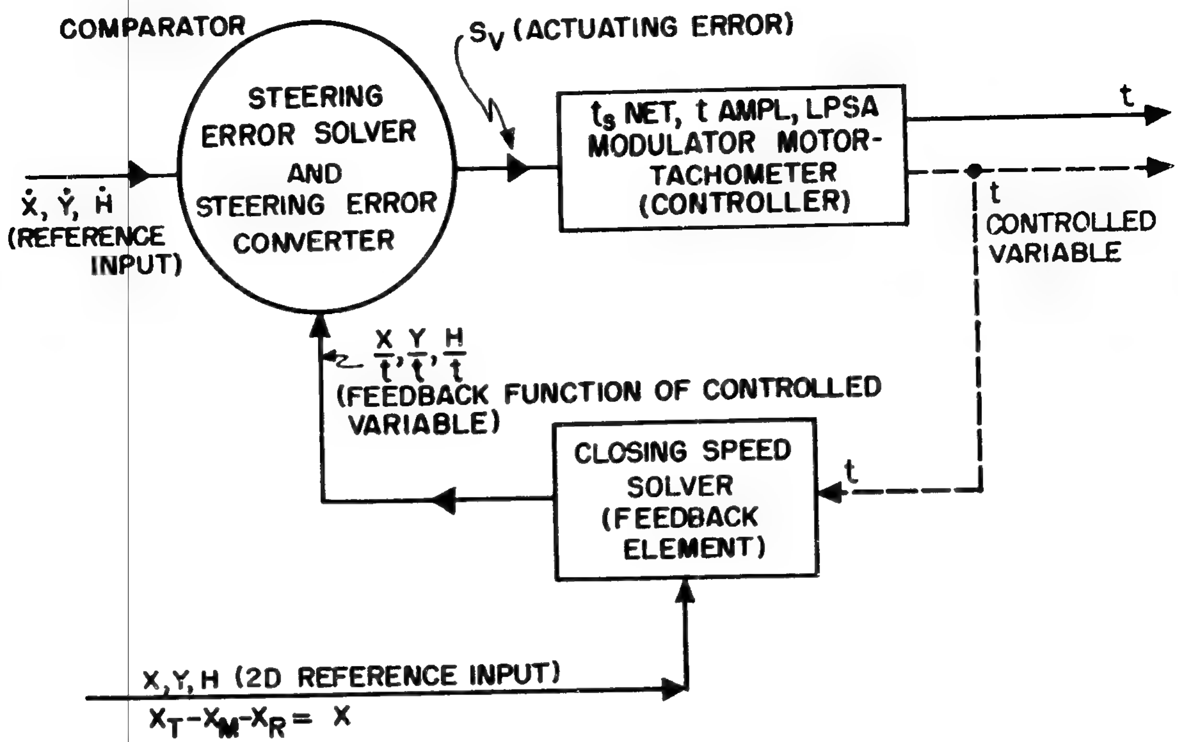


Figure 31. Block diagram, time-to-intercept servomechanism.

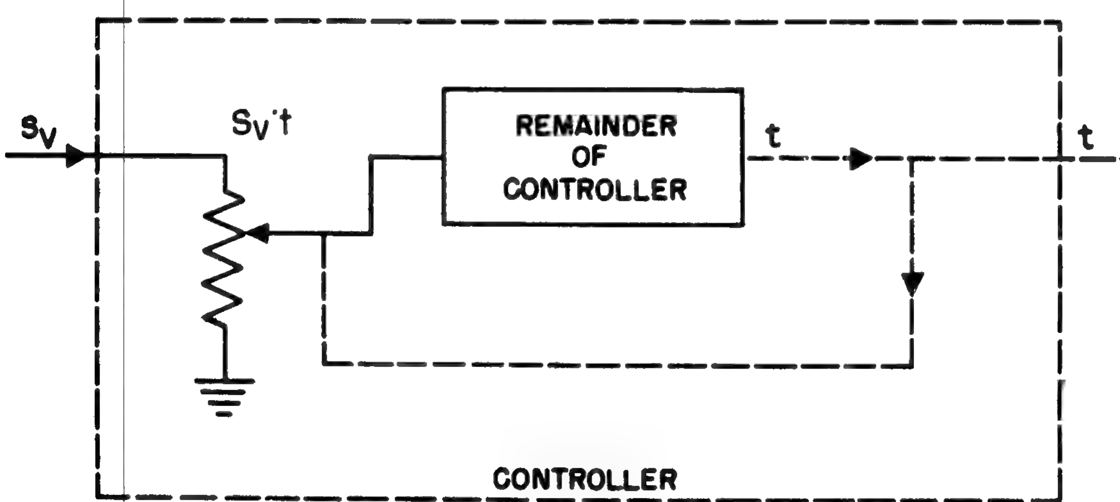


Figure 32. Simplified block diagram of gain compensating feedback loop.

d. Velocity feedback. The third feedback loop (fig 33) within the block representing the controller is perhaps the most important of the three feedback loops, when considering what the time-to-intercept servo is required to accomplish. This third feedback loop causes the shaft of the time-to-intercept servo to turn at the same speed as the shaft that drives the second hand of a clock. This speed is equivalent to 1 second per second. Consider the face of a clock which is divided into 60 graduations marked about the circumference of the clock. Each graduation represents 1 second of time. If, at 1200, a clock is running precisely on correct time, the second hand will point at the 1200 mark. One second later the hand will point at mark 1, two seconds later at mark 2, three seconds later at mark 3, and so on around the clock. Translated into computer language, a second-per-second rate of the time-to-intercept servo means that, for each second of time, the shaft of the time-to-intercept servo will move the brush arm of a time potentiometer a distance corresponding to 1 second. During the flight of the missile, the t-servo must operate at a second-per-second rate to send the burst order at the exact time desired. At the instant the fire command is given (missile still in the launcher), the shaft of the time-to-intercept servo assembly is set at a position corresponding to the time remaining to intercept at MISSILE AWAY + 4 (approximately FIRE + 7 seconds). The basic assumption is that the missile will have roll stabilized within 7 seconds after the fire command. The dead-time unit is set up on this basis and it clocks down for exactly 7 seconds after FIRE. By so doing, the dead-time unit, in effect, freezes the intercept point in space and permits the shaft of the time-to-intercept servo assembly to remain fixed until the missile is stabilized. (As has been pointed out previously, the shaft position may change if the target makes a maneuver during the 7-second interval after FIRE.) After the MISSILE AWAY + 4 signal is received, the missile dives toward the target, and the time remaining to intercept begins to decrease. Therefore, the shaft of the time-to-intercept servo must begin to turn in the direction of decreasing time at a second-per-second rate. When the missile is on trajectory, guidance begins, and the movement of the time shaft is controlled by the actuating error signal S_V. Computation of time to intercept continues until t is equal to 0.25 second. At this time, the actuating error S_V is removed and the shaft must again turn like the second hand of a precision clock until it reaches zero. The accuracy of time to intercept is most important from $t = 0.25$ to $t = 0$, because the time at which the burst order is sent is determined by the time-to-intercept servo.

e. Velocity feedback block diagram. The block diagram of the circuits that cause the servo to turn at a second-per-second rate is shown in figure 33. This type feedback is called velocity feedback. The starting point in the discussion of figure 33 is the instant of time that the FIRE command is given. The shaft of the t-servo is positioned to the predicted intercept time computed by the time-of-flight predictor. An open circuit exists between the time potentiometer and the

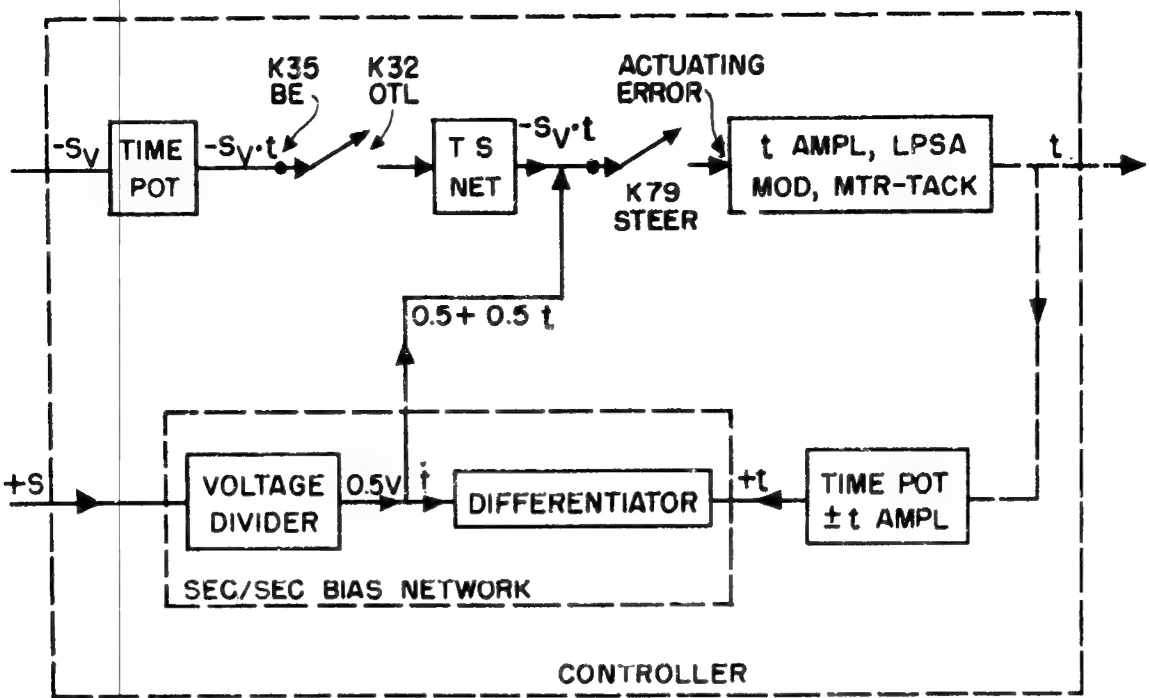


Figure 33. Velocity feedback circuits for obtaining second-per-second clockdown.

t_s network because the contact of K32 (on-trajectory locking relay, shown as a switch) is open. The scale factor voltage, +S, is applied to a resistive voltage divider. The mechanical position of the t-servo shaft is applied to the block that represents another time potentiometer and to the plus and minus t-amplifiers. When the shaft is fixed, the output voltage, +t, is constant. The +t-voltage is applied as an input to the differentiator, which is an R-C network. Since t is constant, the output of the differentiator, ṫ, will be zero. An open circuit exists between the voltage divider and the large block that represents the t-amplifier, low-power servoamplifier, etc. The open circuit exists because the contact of steer relay K79 is open. During the first 7 seconds after FIRE, it is assumed that the target does not change course; therefore, t will be unchanged. (The input to the controller from the time-of-flight predictor is not shown to simplify the diagram as much as possible, and with the assumption that the target course remains unchanged so the value of the input from the time-of-flight predictor will also remain unchanged.) At MISSILE AWAY + 4, the steer relays energize and the contacts of K79 close. The closing of these contacts permits the output of the voltage divider (at this instant, a small fraction of +S) to be applied to the remainder of the controller. When this voltage is applied, the shaft of the t-servo begins to turn in the direction of decreasing time. The turning of the shaft changes the position of the brush arm on the time potentiometer,

causing the output of the plus and minus t-amplifiers to decrease. Since the +t input to the differentiator is decreasing, the output voltage, $\dot{t}$, will be negative. This voltage is compared in the t-amplifier with the fraction of the +S-voltage. If these two voltages do not add up to zero, the resulting error voltage will change the speed at which the position of the output shaft is changing until the error voltage becomes zero. The fraction of the +S-voltage which is compared with t is chosen so that when the error is zero, the output shaft turns at a second-per-second rate. When the missile reaches on trajectory, the contact of K32 closes and the servo rate is corrected by the $-S_V$ voltage. If S_V is not zero, it will combine with the input from the velocity feedback network and cause the time servo to change speed until the output shaft is driven to the correct position. If S_V is zero, the output of the velocity feedback network will control the shaft, causing it to turn at a second-per-second rate. When t is equal to 0.25 second, the contact of K35 (burst enable relay) opens, removing the actuating error voltage, $S_V \times t$. From this time on, the error from the velocity feedback network controls the position of the shaft and insures accurate clocking down to zero.

65. DETAILED OPERATION OF THE $-S_V$ SUMMING AMPLIFIER (TM 9-5000-26, p 78)

The $-S_V$ summing amplifier consists of the amplifier and its associated input network, both of which are designated by the symbol $-S_V$. If added together arithmetically, the voltages that appear at terminals 3, 4, and 5 of the input network would yield a voltage representing $+S_V$. The scale factor of these input voltages is 25 mv/yd/sec. Thus, if the voltage were measured at terminal 3 with the null voltage test set (NVTS) and found to be 10 volts, the component of S_V at terminal 3 is $\frac{10}{25} \times 1{,}000$, or 400 yards per second. The resulting output is $-S_V$ multiplied by the d-c gain factor of 14 1/3. This multiplying factor is obtained by tapping the voltage at the junction of R158 and R159 and feeding it back to terminal 2 of the input network. Capacitor C158 reduces the gain of the summing amplifier at frequencies above direct current, and reduces the gain appreciably at frequencies above 16 cycles per second. The network consisting of CR140, R142, and R143 is a conventional limiting network. No adjustments are required in this circuit.

66. DETAILED FUNCTIONAL OPERATION OF THE CONTROLLER (TM 9-5000-26, p 83)

During the steering phase of computer operation, the controller consists of the t_s input network, the t-amplifier, the modulator, the low-power servoamplifier, the servomotor generator assembly and its output shaft and loads. The operations of the modulator, low-power servoamplifier, and servomotor generator

are discussed in TM 9-5000-14. In the following discussion, it is assumed that the computer steering section is in control of the missile. The t-potentiometer T_C-7A, is at the input network to the t-amplifier. At the brush arm of this potentiometer (driven by the t-shaft), a voltage is tapped off, which is proportional to the quantity $-S_V \times t$. This voltage passes through the closed contacts of K35, contacts of K32 (always energized after on trajectory), and contacts of K33 (always closed except during testing procedures). The potentiometer provides the compensation for the increase of gain as time decreases in the closing speed solver. The voltage which represents $-S_V \times t$ enters the t_s input network on terminal 3. The ratio of the input and feedback resistors in the input network is 1:1; however, the d-c gain of the t-amplifier circuit is established by tapping the output voltage off at the junction of R64 and R63, and feeding it back to the input network on terminal 2. This circuit arrangement produces a d-c gain factor of 1,471. The t-limiter limits the output voltage when it exceeds ±30 volts. If S_V is a positive quantity, the input to terminal 3 of the t_s network will be a negative voltage and the output of the t-amplifier will be a positive voltage. As indicated on the schematic diagram, a positive output from the t-amplifier will cause the servomotor generator to be driven in the direction of increasing time. As the shaft turns to increase time, the ideal closing velocity decreases and causes the voltage representing S_V to approach zero.

67. DETAILED OPERATION OF THE VELOCITY FEEDBACK LOOP (TM 9-5000-26, p 83)

a. <u>±t-amplifiers</u>. The elements which comprise the velocity feedback loop are discussed in simplified form in paragraph 64, and are shown in simplified form in figure 33. In the following discussion, the starting point is at MISSILE AWAY + 4. During the 7 seconds from FIRE to the starting point of this discussion, the shaft of the time servo will be considered as fixed in the position established by the time-of-flight predictor (time to intercept computed from roll stabilization), so that voltage tapped off potentiometer T_C-14 is constant. On the schematic diagram, this voltage is indicated as $S \cdot t$. The scale factor voltage (+S) is applied across T_C-14B. The +S-voltage, 106 2/3 volts, enters the servo cabinet at terminal 607. The potentiometer is designed so that for every second of time 1 volt is tapped off the potentiometer. Thus, when t is 100 seconds, 100 volts is tapped off; if t is 42 seconds, 42 volts is tapped off. The $S \cdot t$ voltage is applied to terminal 3 of the -t-input network until time to intercept decreases to 24 seconds. At t = 24 seconds, the circuit between the -t-input network and T_C-14B is opened, and a circuit between T_F-6 and the -t-input network is closed. These simultaneous actions are accomplished by fine relay K38. When t = 24 seconds, the voltage tapped off T_F-6 is 24 volts, and when t = 10 seconds, the voltage is 10 volts. Thus, the scale factor of T_C-14B and T_F-6 is 1 volt per second. The plus and minus t-amplifiers perform the functions of isolation and sign inversion. Each has a d-c gain of one. These

amplifiers, besides being a part of the velocity feedback loop, produce voltages (plus and minus t) with a scale factor of 1 volt equals 1 second. The plus and minus t-voltages are fed to various parts of the computer as indicated on the schematic.

b. +S-voltage input. The +t-voltage is one of the two inputs to the second-per-second bias network; the other input is the scale factor voltage, +S, which is applied across a voltage divider in the second-per-second bias network. This voltage divider extends between terminal 3 and terminal 5 of the second-per-second bias network. The voltage tapped off at the junction of the 2.0-megohm resistor and the 1.0-megohm resistor may be adjusted between the limits of 0.502 and 0.504 volt by changing the value of the resistance labeled 0 - 400. This adjustment is made at the factory and should not be changed by battery maintenance personnel. This voltage is the reference voltage input developed across the 1.0-megohm resistor in the second-per-second bias network. The resistor acts as an input resistor in the input circuit to the t-amplifier.

c. Circuit operation. At MISSILE AWAY + 4, the circuit between terminal 1 of the second-per-second bias network and the t-amplifier is closed through K79, the steer relay, which is energized at MISSILE AWAY + 4. If the shaft of the time-to-intercept servo is fixed at the instant just before MISSILE AWAY + 4, the input to the t-amplifier will be approximately +0.5 volt from +S. After amplification in the t-amplifier and the controller, this input voltage will cause the shaft to the t-servo to accelerate in the direction of decreasing time. The subsequent shaft motion will cause a time rate of change in the +t-voltage to be applied to terminal 2 of the second-per-second bias network. The 0.5-microfarad capacitor connected between terminals 1 and 2 of the second-per-second bias network, the feedback resistor (1.0-megohm) connected between terminals 2 and 1 of the t_s input network, and the t-amplifier are the elements which comprise a differentiating network of the type discussed in TM 9-5000-13. The +t-voltage is the input to this circuit; therefore, the output will be proportional to -RC x $\dot{t}$ or $-0.5\dot{t}$. Since time is decreasing, the time rate of change of +t at the input, $\dot{t}$, will be negative, and the output of the t-amplifier caused by t alone will be positive. The output of the t-amplifier due to the 0.5-volt (approximately) reference input alone will be negative. When $\dot{t}$ is equal to the reference input, 0.5 volt, the output of the t-amplifier is zero and the shaft of the time servo no longer accelerates, but turns at a constant velocity so that the shaft moves at a second-per-second rate. The following numerical example illustrates the action of the second-per-second bias network:

(1) At MISSILE AWAY + 4:

Output of t-amplifier: -1,471 x 0.5 volt.
Initial setting of shaft: 50 seconds (time to intercept).
The time servo will accelerate in the direction of decreasing time.

(2) At MISSILE AWAY + 4.5:

Time to intercept:	49.5 seconds.
Shaft position:	49.75 seconds.
Plus t:	49.75 volts.
$\dot{t}$:	-0.25 volt in 0.5 second, or -0.5 volt per second.
Output of t-amplifier caused by t:	-1,471 x (0.5 x -0.5), or -1,471 x (-0.25).
Total output of the t-amplifier:	-1,471 x (0.5 - 0.25), or -1,471 x 0.25.

The time servo must continue to accelerate in the direction of decreasing time.

(3) At MISSILE AWAY + 5:

Time to intercept:	49 seconds.
Shaft position:	49 seconds.
Plus t:	49 volts.
t:	-0.75 volt in 0.5 second, or -1.5 volts per second.
Output of t-amplifier resulting from $\dot{t}$:	-1,471 x (0.5 x -1.5), or -1,471 x (-0.75).
Total output of the t-amplifier:	-1,471 x (0.5 - 0.75), or -1,471 x (-0.25).

The time servo must decelerate or slow down.

(4) At MISSILE AWAY + 5.5:

Time to intercept:	48.5 seconds.
Shaft position:	48.5 seconds.

Plus t:	48.5 volts.
$\dot{t}$:	-0.5 volt in 0.5 second, or 1 volt per second.
Output of the t-amplifier caused by $\dot{t}$:	-1,471 x (0.5 x -1), or -1,471 x (-0.5).
Total output of the t-amplifier:	-1,471 x (0.5 - 0.5), or 0.

The time servo is not required to accelerate, but it will turn at a constant velocity so that the time setting changes at a second-per-second rate.

68. MECHANICAL OPERATION

An additional action of the time-to-intercept servo is to operate switches at times to intercept of 24 seconds, 10 seconds, 0.25 second, and zero seconds. These switches are operated by cams mounted on the gear wheels of the time-to-intercept servo. The switches are shown schematically in TM 9-5000-26, pages 108 and 109.

a. <u>t = 24 seconds</u>. When time to intercept is 24 seconds, S3 closes. As a result, the following relays energize:

K38 (fine), located in the steering computer switching relay panel;
K1, located in the position difference relay panel;
K2, located in the position difference relay panel;
K3, located in the position difference relay panel; and
K1, located in the order-shaping network panel.

When K38 is energized, the fine-time potentiometer, T_F-6, replaces the coarse potentiometer, T_C-14B, in the second-per-second feedback loop. When K1, K2, and K3 energize, the fine-time cards replace the coarse-time cards in the closing speed solver. When K1 in the order-shaping network panel is energized, 1-second order shaping is applied to the circuits of the fin order solver.

b. <u>t = 10 seconds</u>. When time to intercept is 10 seconds, S4 closes, and as a result, K2 in the order-shaping network panel is energized. This action causes the 1-second order shaping to be replaced by 2-second order shaping in the circuits of the fin order solver.

c. t = 0.25 second. When time to intercept is 0.25 second, S7 closes, and as a result, the following relays are energized:

K35, in the steering computer switching relay panel, and
K4, in the indicated error at burst relay panel.

When burst enable relay K35 energizes, the input to the t_s input network (S_V x t) is removed and the burst order circuit is enabled. When K4 is energized, the target prelaunch velocity components are removed from the event recorder.

d. t = 0 seconds. When time to intercept is 0 (shaft of time-to-intercept servo is at 0 seconds), S8 closes, and the following relays energize:

K1 ZS, K2 ZS, and K3 ZS, all in the indicated error-at-burst relay panel; and
K4 ZSL, in the relay and limiter panel.

When these relays are energized, the apparent miss distance is recorded on the event recorder.

Section XII. BURST ORDER CIRCUIT

69. GENERAL

The final output of the computer is the burst order which is transmitted via the missile-tracking radar to the missile in flight. The burst order circuit causes the transmission of the burst order to the missile. The components of the burst order circuit are the burst time bias potentiometer, a DC amplifier designated as the C (for comparison) amplifier, a triode called the burst order amplifier, and a number of relays. The burst time bias potentiometer is located at the top of the right swinging frame in the computer amplifier cabinet. The C-amplifier is also located on the right swinging frame. The burst order amplifier and burst indicator amplifier each use half of a 5687 twin triode, mounted on the computer conditioning relay panel. This relay panel is located on the right rear frame in the computer amplifier cabinet. The two inputs to the burst order circuit are a d-c voltage tapped off a potentiometer by a brush arm driven by the time-to-intercept servo, and a d-c voltage (burst time bias) tapped off the burst time bias potentiometer. The burst time bias is established by the setting of a knob, which is a part of the burst time bias potentiometer. This knob is adjusted by the battery commander and may be set to provide values of burst time bias between the limits of 0 and 200 milliseconds. The output of the burst order circuit is a surge of direct current, which causes the transmission of the burst order to the missile via the missile-tracking radar (MTR). The physical path of the burst order after it leaves the computer

is from the computer through switches on the battery control console to J19 on the battery control trailer junction box. The signal continues on from J19 over cable run number 34 and enters the radar control trailer at J4 in the main junction box on the road side of the trailer. The signal is then applied to the combining amplifier in the MTR console. The scale factor in the burst order circuit is 0.05 volt per millisecond. Thus, if the burst time bias potentiometer is set at 200 milliseconds, 10 volts is tapped off the potentiometer. The switches on the battery control console permit the battery control officer to delay the burst or to send a premature burst signal whenever such action is necessary.

70. SIMPLIFIED FUNCTIONAL OPERATION

A simplified block diagram of the burst order circuit is shown in figure 34. The burst order circuit produces the burst order when time to intercept is equal to the burst time bias set into the computer by the battery control officer. The input voltages to the burst order circuit are a positive voltage tapped off a potentiometer in the time-to-intercept servo and a negative voltage tapped off the burst time bias potentiometer. At times to intercept of 0.25 second (250 milliseconds) or greater, the positive voltage input is constant in value and always greater than the burst time bias. The positive and negative input voltages are compared, amplified, and inverted in the C-amplifier. At times to intercept of 0.25 second, or greater, the output of the C-amplifier will be approximately -30 volts. The burst order amplifier and the burst indicator amplifier are biased by the output voltage of the C-amplifier, and are always cut off when the output voltage is -30 volts. The burst order relay is in the output circuit of the burst order amplifier and will energize only when enough current flows through the relay coil. Therefore, at times to intercept of 0.25 second, or greater, no burst order can be sent. As time to intercept becomes less than 0.25 second, the positive voltage decreases. When time to intercept has decreased to a value approximately 24 microseconds greater than the burst time bias setting, the limiting action in the C-amplifier circuit ceases and the output voltage changes from -30 volts to a less negative value. When time to intercept is equal to burst time bias, the output of the C-amplifier will be approaching zero. Zero bias on the burst order amplifier and the burst indicator amplifier will allow the amplifiers to pass enough current to energize the burst order relay and the burst indicator relay. This action causes the burst order to be sent to the missile and provides a visual burst indication in the battery control and radar control trailers.

71. DETAILED FUNCTIONAL OPERATION (TM 9-5000-26, pp 83 and 109)

The circuit that provides the burst time bias is located at 83D3. Burst time potentiometer R322 is a 13,000-ohm potentiometer which is handset with a knob. The series combination of R327 and R328 is in parallel with R322.

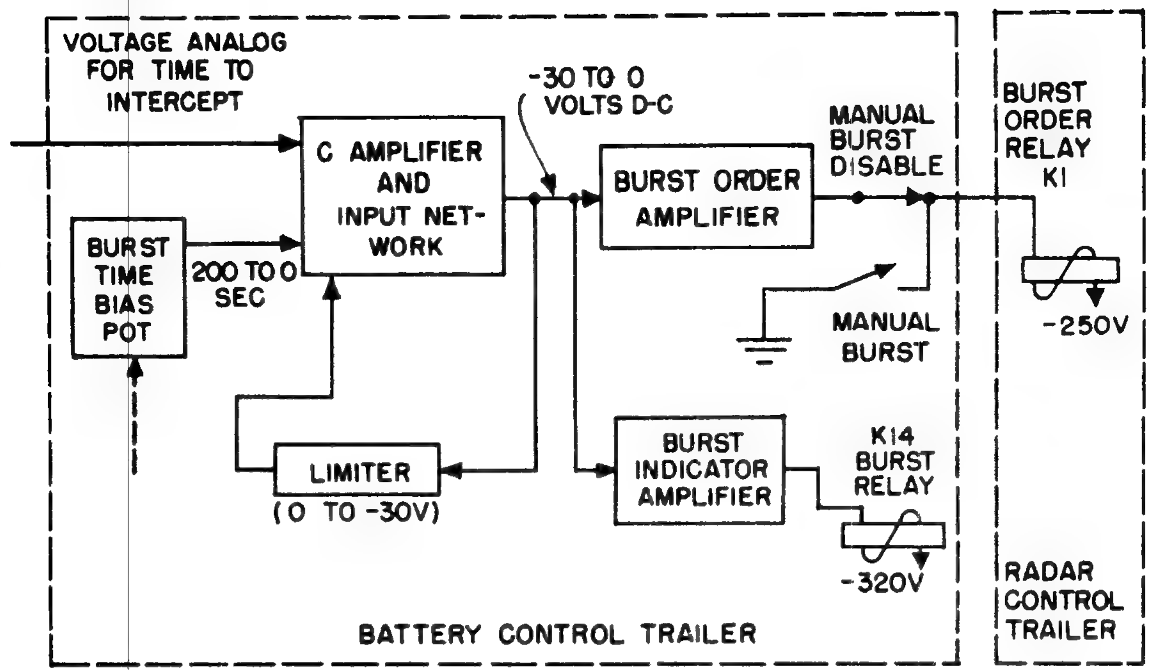


Figure 34. Burst order circuit, simplified block diagram.

Resistor R328 is a padding resistor, which may be set to any value between 60 and 600 ohms. The actual value of this resistance is established at the factory, and battery maintenance personnel are not authorized to make this adjustment. However, the method of adjustment is shown on the schematic for information purposes. The remainder of the voltage divider network consists of R325 and R326. The voltage placed across the entire voltage divider network is -250 volts. This voltage comes from the ±250-volt regulator. The value of R328 is correct when the potential at terminal 4 of the burst time bias potentiometer is -10 volts. Since the scale factor is 0.05 volt per millisecond, this -10-volt value represents a maximum burst time bias setting of 200 milliseconds. The voltage applied to terminal 2 of the C-input network may be negative or zero, but never positive. To make sure that the burst order will be sent at the instant desired by the battery control officer, the computer time to intercept must be compared with the time established by the setting of the burst time bias potentiometer. The voltage that represents time to intercept and is compared with the burst time bias voltage is obtained from potentiometer card T_F-7. This is a fine-time card similar to T_F-6. A resistance of 31,376 ohms is tapped to this card at a point representing a time to intercept of 250 milliseconds. The +S voltage (8B1) 106 2/3 volts, is applied to the top of the 31,376-ohm resistor. No voltage is applied to the top of the T_F-7 card. Therefore, as time to intercept changes from 100 to 75.25, 75 to 50.25, 50 to 25.25, and 25 to 0.25 (seconds) (the potentiometer brush moves between the top of the card and the tap), the voltage tapped off

remains constant. The potential at the 250-millisecond tap is 12.5 volts. This potential establishes the scale factor.

If $$250 \text{ milliseconds} = 12.5 \text{ volts},$$

then $$1 \text{ millisecond} = \frac{12.5}{250} \text{ volts, or } 0.05 \text{ volt}.$$

Thus, the scale factor is 0.05 volt per millisecond. As time to intercept decreases from 75.25 to 75, 50.25 to 50, 25.25 to 25, and 0.25 (seconds) to zero, the brush voltage changes at a rate of 0.05 volt per millisecond. The voltage applied to terminal 3 of the C-input network is a positive voltage decreasing in magnitude, but never going negative. The two inputs to the C-input network are compared in the C-amplifier. The only feedback loop around the C-amplifier is the C-limiter circuit. The limiter circuit limits the output of the C-amplifier whenever the output voltage exceeds -30 volts or becomes positive. Since the gain of the C-amplifier is approximately 20,000, a positive voltage 1.2 millivolts greater than the burst time bias voltage is required to drive the amplifier output to -30 volts. When time to intercept is greater than or equal to 0.25 second, limiting occurs and the output is always -30 volts or slightly more. When time to intercept is less than 0.25 second, limiting still occurs until t has decreased to a value approximately 24 microseconds greater than the burst time bias setting. The output of the C-amplifier will approach zero volts when the time to intercept is equal to the burst time bias setting (when the potential at terminal 3 of the input network is equal to the potential on terminal 2). The output of the C-amplifier will attempt to go positive as time to intercept becomes less than the burst time bias setting; however, limiting action again occurs and the output is held to a positive value so small that, for all practical purposes, the output is zero. A capacitor in the limiting circuit provides a feedback path which prevents the high-gain C-amplifier from oscillating and possibly sending a premature burst signal. Since this capacitor must be charged, the output voltage does not change as rapidly as the input signal; therefore, the output signal is delayed somewhat in time with respect to the input signal. The potential at the output of the C-amplifier becomes the bias voltage for the burst order amplifier and the burst indicator amplifier, which are physically located on the computer conditioning relay panel, the schematic diagram of which is located in TM 9-5000-26, page 123. The burst order amplifier and burst indicator amplifier are biased by the potential at the output of the C-amplifier. When time to intercept exceeds the time established by the burst time bias potentiometer by 24 microseconds or more (the output of the C-amplifier is -30 volts), both tubes are biased for beyond cutoff. The plate supply voltage (+250v) for the burst order amplifier is obtained from the radar control trailer (combining amplifier in the missile console) as shown at 109C13. The plate circuit of the burst order amplifier consists of the burst contacts of calibrate relay K2 and burst order relay K1, as

shown at 109C13. The manual burst disable switch is in the circuit to permit the battery control officer to delay the burst if such action is necessary. The manual burst disable switch is normally closed. Calibrate relay K2 is normally energized only during testing procedures. When time to intercept is 0.25 second, burst enable relay K35 energizes and the circuit between the plate of the burst order amplifier and the plate supply voltage (+250 volts) is enabled. No current will flow in the plate circuit at this time because the bias on the burst order amplifier is still -30 volts. Because T_F-7 can make four revolutions as t changes from 100 to 0, conduction could occur at t = 75, 50, 25, and 0. The presence of contacts of the burst enable relay in the plate circuit of the burst order amplifier insures that no burst order will be sent to the missile until time to intercept is less than 0.25 second. The plate supply voltage for the burst indicator amplifier is +320 volts. Burst relay K14 is in the plate circuit of the burst indicator amplifier. When time to intercept is equal to the burst time bias setting, the bias on the burst order amplifier and the burst indicator amplifier rises above cutoff. As a result of this action, enough current flows in the plate circuits of the burst order amplifier and the burst indicator amplifier to energize the burst order relay and the burst relay, respectively. When the burst order relay is energized, the missile-tracking radar transmits the burst order to the missile. Energizing the burst relay causes other relays to energize. These relays illuminate burst indicator lights on the battery console, the missile-tracking radar control console, and the target-tracking radar console; provide a burst indication signal to the event recorder; and complete the circuits that permit the recording of apparent miss distance on the event recorder.

72. ADJUSTMENT OF BURST TIME BIAS

The battery commander is responsible for setting the burst time bias to obtain the most effective burst. He may direct any subordinate to set the burst time bias, and he may call upon his fire control specialists for advice as to the proper setting for any particular engagement. The chain of events resulting in missile burst is started a few milliseconds before the missile reaches the desired intercept point, because of several time delays. The most important of these delays for an incoming course are:

a. A 5-millisecond delay in information delivered to the computer by the missile-tracking radar.

b. A 2-millisecond delay in information passing through the computer geometric resolution circuits.

c. A 25-millisecond delay in the computer issuing the burst order.

d. A delay of about 62 milliseconds in the missile circuits. This time is variable for each missile, but will be reported from the launching area.

e. A 1.5-millisecond delay in a warhead missile from detonator signal to full explosive intensity. This delay is 5 milliseconds for a spotting charge missile to build up to a light intensity strong enough to show on photographs.

f. A 10-millisecond delay for a warhead round only, to put the lethal center of the exploded warhead at time zero. At a closing velocity of 1,400 yards per second, the error in burst timing is approximately 3 milliseconds, or 5 yards. The total delay for a warhead missile, therefore, is approximately 105.5 milliseconds (varies according to missile delay), and the total delay for missile carrying a spotting charge is approximately 99 milliseconds plus or minus the delay variation of the missile circuit.

CHAPTER 3

LIMITERS, ORDER LIMITING, AND ORDER SHAPING

Section I. GENERAL DISCUSSION

73. GENERAL DISCUSSION

Certain conditions can occur during normal computer operation under which the input signals to a specific DC amplifier stage become large enough either to drive the output stage to saturation, or to cause the grid to draw current. When these actions occur, the amplifier is said to be overloaded. Certain other conditions can occur during computer operation which will result in output voltages larger than necessary for a specific application. These conditions are prevented from interfering with proper computer operation by limiting circuits. Order-shaping circuits are required in the operation of the computer so that the computer will guide the missile back onto an intercept course with very little overshooting when the target executes an evasive maneuver. Since the precision of the computer and satisfactory missile guidance from the ground depend upon the continuous and proper operation of the limiting and order-shaping circuits, it is imperative that maintenance personnel know how these circuits operate and are able to keep them operating properly at all times.

Section II. LIMITERS

74. GENERAL

There are some instances in the Nike I computer when normal input signals to a DC amplifier would cause it to overload. (Overloading is undesirable since it causes faulty automatic zero setting.) There are other instances when it is necessary to limit the DC amplifier output to a specific value. Limiting circuits are used in the computer to prevent overloading and to limit outputs to specific values. Limiting circuits greatly reduce the gain of the DC amplifier before the output voltage can reach the overload value. Limiting to a specified value below the overload value is required for DC amplifiers that are used as comparators in servo loops. Here the limiting action is necessary to avoid overloading of the other components in the servo loop when a large error exists.

75. OVERLOADING

A DC amplifier is said to be overloaded when the resultant input voltages are so large that the DC amplifier cannot deliver a feedback current equal to the total input current. Figure 35 shows a typical DC amplifier output circuit. It consists of one-half of a 5687 output tube, feedback resistor R_B, plate feed

resistor R_P, and load resistor R_L. The maximum positive output voltage will be obtained when the tube is cut off, and the maximum negative output voltage will be obtained when the grid is at cathode potential. The value of R_P equals 24,660 ohms in all cases. The value of R_B is at least 20 times larger. (Feedback resistors are usually 0.5 or 1.0 megohm.) The maximum positive output is, therefore, determined primarily by the value of R_L. In most cases, R_L is much smaller than R_B and the maximum output voltage (obtained when the tube

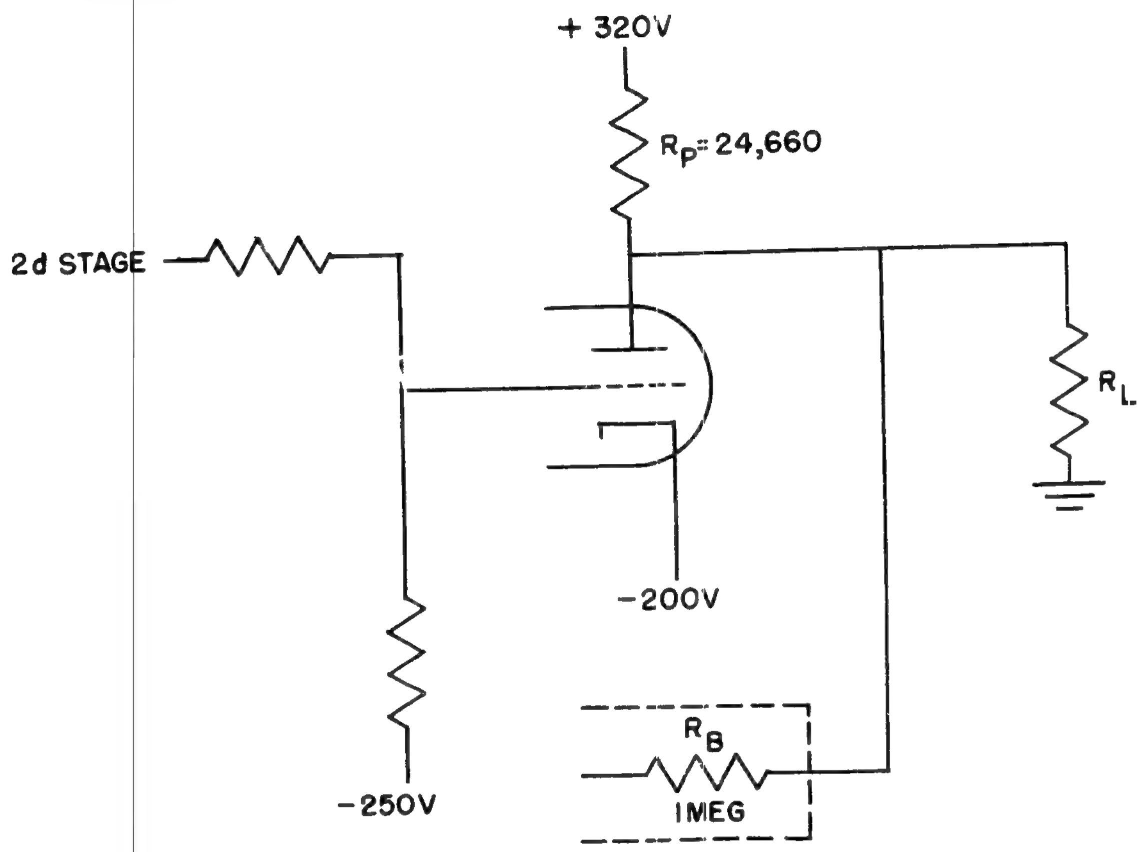


Figure 35. Output stage of DC amplifier.

is cut off) is very nearly 320 x $\frac{R_L}{R_P + R_L}$. A normal value for this maximum voltage is +125 volts. When the output tube is operating with zero grid-to-cathode voltage (drawing grid current) the tube resistance is low and the tube will draw current through R_P and R_L. The negative overload value is not nearly as dependent upon R_L as the positive overload value is. In most cases, the voltage drop across the tube will be close to 50 volts under this condition, so that the maximum negative output voltage is approximately -150 volts.

76. EFFECTS OF OVERLOADING

The output voltage of a DC amplifier is the correct mathematical function of the inputs if the summing point (the input grid to the amplifier) is very close to zero potential. The summing point is held at zero potential by the amplifier, because the amplifier establishes a voltage at the output plate. This causes a current to flow through the feedback resistor between the summing point and the plate. This current is equal to the sum of the input currents flowing through the input resistors to the summing point. This balanced condition can be fulfilled only as long as the output voltage lies between the maximum positive voltage and the maximum negative voltage that the amplifier can deliver. If the values of the input voltages produce an output voltage outside of these limits, the amplifier is in an overload condition and the input grid of the amplifier cannot be held near zero potential. One result of overloading is that the amplifier no longer performs the mathematical operation it is supposed to perform. However, this situation cannot be helped, since limiting the output voltage below the overload value will not eliminate the mathematical inaccuracy. A second result of overload is that the voltage existing at the input grid, which can no longer be compensated for by the zero-setting circuit, affects the zero-setting circuit so that it cannot operate properly for several seconds after the amplifier overload is removed. Thus, even if the input values change so that the amplifier could operate on them in the normal and correct fashion, the zero-setting circuit will prevent the amplifier from operating correctly for considerable time after overloading.

77. AUTOMATIC ZERO-SET ACTION DURING OVERLOAD

The automatic zero-setting circuit amplifies the voltage at the summing point and applies the amplified offset voltage to a storage capacitor connected to the compensating grid of the first stage of the DC amplifier. If the overload condition lasts very long, the efforts of the zero-setting circuit to restore zero potential at the input grid result in an abnormally high charge on the storage capacitor. When the input signals to the amplifier change so that the amplifier could theoretically resume normal operation, the voltage across the storage capacitor is much greater than that required for offset voltage compensation under normal conditions and a wrong value of output voltage will result. The period of faulty amplifier operation under a postoverload condition would last until the AZS amplifier could remove the abnormal charge from the storage capacitor. Removal of excess charge could take several seconds and therefore cannot be permitted.

78. TYPES OF LIMITING CIRCUITS

The Nike I computer uses two types of limiting circuits for the limiting functions just discussed: diode limiters and varistor limiters. Diode limiters are

used when it is necessary to limit sharply or when an accurate threshold value for the limiting action is required. Varistor limiters are used when it is necessary to limit gradually. They start to reduce amplifier gain at +30 volts.

Section III. DIODE LIMITERS

79. GENERAL

The Nike I computer uses eight diode-limiter circuits. The amplifiers in the computer which operate with diode limiters are the G_Y, G_P, $-S_T$, C, OT, CTA, t, and +OL amplifiers. The eight diode limiters are contained in three limiter panels. A limiter is placed close to its associated amplifier to minimize the length of the shielded lead between the amplifier input and the limiter.

80. OPERATION OF THE t-LIMITER

The principles of diode limiter operation are the same for all of the limiters. The operation of the t-limiter will be discussed in detail to bring out the basic principles. The t-limiter functional schematic is shown on page 83 of TM 9-5000-26. It limits the output of the t-amplifier whenever the output goes above +30 volts or below -30 volts. The detailed circuit schematic of the t-limiter is shown on page 86 of TM 9-5000-26.

81. THE TUBE

Tube V2, a 5755 twin triode, is operated as a twin diode by connecting the plate and grid of each section together. The reason for using this type of tube is that, unlike available diodes, it meets the extremely stringent back-resistance requirement in this circuit application. Leakage current through the diodes will impair computer accuracy because it will add to or subtract from the currents at the summing point. The nonconducting diodes must be considered as an extremely high but not infinite resistance, shunting the feedback resistance of the t-amplifier. The value of this back-resistance will affect the total feedback resistance of the circuit and, thus, will affect the all-important resistance ratio between input resistance and feedback resistance. For the diode back-resistance to be negligible, it must be extremely high. The back-resistance that is tolerable is different in different applications, but there are instances where a back-resistance of 4,000 megohms is the lowest allowable value. The type 5755 triode connected as a diode meets this extremely high back-resistance requirement.

82. LIMITING ACTION

Refer to TM 9-5000-26, page 86. The output of the t-amplifier is limited by the conduction of the diodes in the t-limiter. When the output of the t-amplifier exceeds 30 volts, the A-section of V2 (pins 1, 2, and 3) will conduct. This action will place the series combination of the diode resistance (practically negligible) and R7 in parallel with the normal feedback path of the amplifier. Since the resistance of R7 is considerably smaller than the effective resistance of the normal feedback circuit, the effective total feedback resistance is reduced to a value slightly less than that of R7 alone. The effect of this action is to reduce the gain of the t-amplifier to a value less than 1/10. Therefore, for all practical purposes the output remains at 30 volts until the overload condition stops.

83. DETERMINATION OF THRESHOLD VOLTAGE

The value of the t-amplifier output voltage at which limiting occurs is known as the threshold voltage. It is not immediately obvious, from looking at the schematic, that the threshold voltage is ±30 volts. Consider the biasing arrangement for the B-section of V2. Pin 7 of V2 is connected to the t-amplifier grid, which is held close to zero potential by the action of the zero-set unit. The plate (pin 8) is connected to the junction of R8 and R10. The figure in parentheses on the schematic (-27) represents the potential existing at pin 8 when the t-amplifier output is zero. The voltage divider, consisting of R10 and R8, between -250 volts and the output voltage of the t-amplifier establish the potential at the plate of the B-section of V2. When the output of the t-amplifier is zero, the B-section of V2 is cut off by the -27 volts. This section of V2 will conduct when the potential at pin 8 rises above zero. For the potential at pin 8 to be zero, enough current (about 1 ma) from the -250-volt source must pass through R10, a 0.249-megohm resistor, to develop 250 volts across R10. This same current must also flow through R7 (30,100 ohms) to the potential at the output of the t-amplifier. A potential of 30 volts is required at the output of the t-amplifier to draw the required amount of current from the -250-volt source through R10 and R8. The same reasoning can be applied to the R9 and R7 voltage divider to determine that the negative threshold voltage is -30 volts. Were it not for varistor CR1B, the potential at pin 2 of V2 would be -27 volts when the output of the t-amplifier is zero. However, the varistor draws current and reduces the potential at pin 2 to the value indicated in parentheses (+15).

84. PURPOSE OF CR1B

The varistor is connected from cathode 2 of V2 to ground to keep the cathode-to-filament voltage lower than 70 volts. Cathode 7, which is tied to the summing point (t-amplifier grid), is always very close to zero potential. The filament,

which is heated by alternating current, is also at zero average d-c potential. Therefore, the d-c voltage between cathode 7 and filament is always negligible. The d-c potential at cathode 2 varies as the output voltage of the t-amplifier varies. This cathode potential goes only slightly negative, since the A-section starts to conduct as soon as cathode 2 is slightly negative, and then there exists a low-resistance connection from the cathode through the tube to the summing point, the latter being at virtual ground. As the t-amplifier output voltage increases from the negative threshold value, which is -30 volts, the potential at cathode 2 goes positive. As the output voltage becomes more positive, CR1B conducts more current and reduces the potential at pin 2. A varistor has the characteristic of being a high resistance when the voltage across its terminals is low, and a low resistance when this voltage is high. When the t-amplifier output voltage has exceeded the negative threshold, V1A (pins 1, 3, and 2) conducts, cathode 2 is slightly negative, and the voltage across the varistor is low, making the varistor a very high resistance. Accordingly, CR1B has no effect on the threshold value. It also has no effect on the limiting action of the diode. The operation of the varistor is similar to that of a clamping circuit.

85. REDUCTION OF HEATER VOLTAGES

Resistors R1, R6, and R11 in the heater circuits of V1, V2, and V3 reduce the filament voltage on the tube with which they are associated. Limiter tubes are operated at reduced filament voltage to hold the leakage current from heater to cathode to a minimum value.

86. +OL AND $-S_T$ LIMITERS

The schematic diagrams of the +OL and $-S_T$ limiters are on page 86 of TM 9-5000-26. The +OL limiter is also shown at 81B11. The $-S_T$ limiter is shown functionally at 79A4.

87. +OL LIMITER

A more detailed explanation of the operation of the OL limiter is presented in section VIII, as a part of the detailed discussion on order limiting.

88. $-S_T$ LIMITER

The $-S_T$ limiter limits the output of the $-S_T$ amplifier when the output voltage exceeds ±87 volts. The threshold values are established by R4 and R2 for the negative value, and by R5 and R3 for the positive value. The limiting action is required for operation of the $-S_T$ amplifier as part of the initial-turn control circuit during the initial turn phase of computer operation.

89. OT AND CTA LIMITERS

The detailed schematic diagrams of the OT and CTA limiters are in TM 9-5000-26, page 88. The OT limiter is shown functionally at 79D6. The CTA limiter is shown functionally at 97A7.

90. OT LIMITER

The OT limiter is shown as the top schematic on page 88 of TM 9-5000-26. It is similar in operation to the t-limiter. One threshold voltage is established at zero because the B-section of V1 (pins 6, 7, and 8) is connected directly between the summing point and the output terminal of the OT amplifier. Therefore, this section will conduct when the output voltage rises above zero. The relative values of R2 and R3 establish the negative threshold voltage at -50 volts. The number in parentheses (+20) at the junction of R2 and R3 indicates the potential at that point when the output of the OT amplifier is zero.

91. CTA LIMITER

The CTA limiter is shown as the bottom schematic. Resistors R5 and R6 establish the positive threshold value at +25 volts. The negative value, -25 volts, is established by R7 and R8. The numbers in parentheses indicate the potentials at those points when the CTA output voltage is zero.

92. C-LIMITER AND G_Y AND G_P LIMITERS

The C, G_Y, and G_P limiters schematics are shown on page 87 of TM 9-5000-26. The C-limiter is also shown functionally at 83D4. The G_Y and G_P limiters are discussed in detail in section V, which deals with order limiting.

93. C-LIMITER

The C-limiter limits the output of the C-amplifier when the output exceeds zero or -30 volts. This limiter is shown in the top schematic on page 87 of TM 9-5000-26. The zero threshold voltage is established by the connection of pin 8 of V1 to the output of the C-amplifier. Resistors R2 and R3 establish the negative value of the threshold voltage at -30 volts.

Section IV. VARISTOR LIMITERS

94. GENERAL

Varistor limiters are used in the Nike I computer to limit the DC amplifier output voltage within specified limits. A varistor limiter is not as effective as

a diode limiter in limiting the output voltage, because varistor limiters do not have a sharp cutoff characteristic.

95. CHARACTERISTICS

The varistor is a high resistance when the voltage across its terminals is low and is a low resistance when the voltage is high. Figure 36 shows a typical current-voltage characteristic for a varistor. When the voltage across the varistor terminals reaches a specified value, the resistance of the varistor decreases rapidly. Since the varistor is connected from the output circuit to the input circuit of the DC amplifier, it is in parallel with the feedback resistor. A typical circuit using a varistor limiter is the A_G amplifier shown on page 49 of TM 9-5000-26. Above the breakdown potential of the varistor, the total feedback resistance, consisting of the normal feedback network in parallel with the varistor, decreases rapidly, causing limiting action.

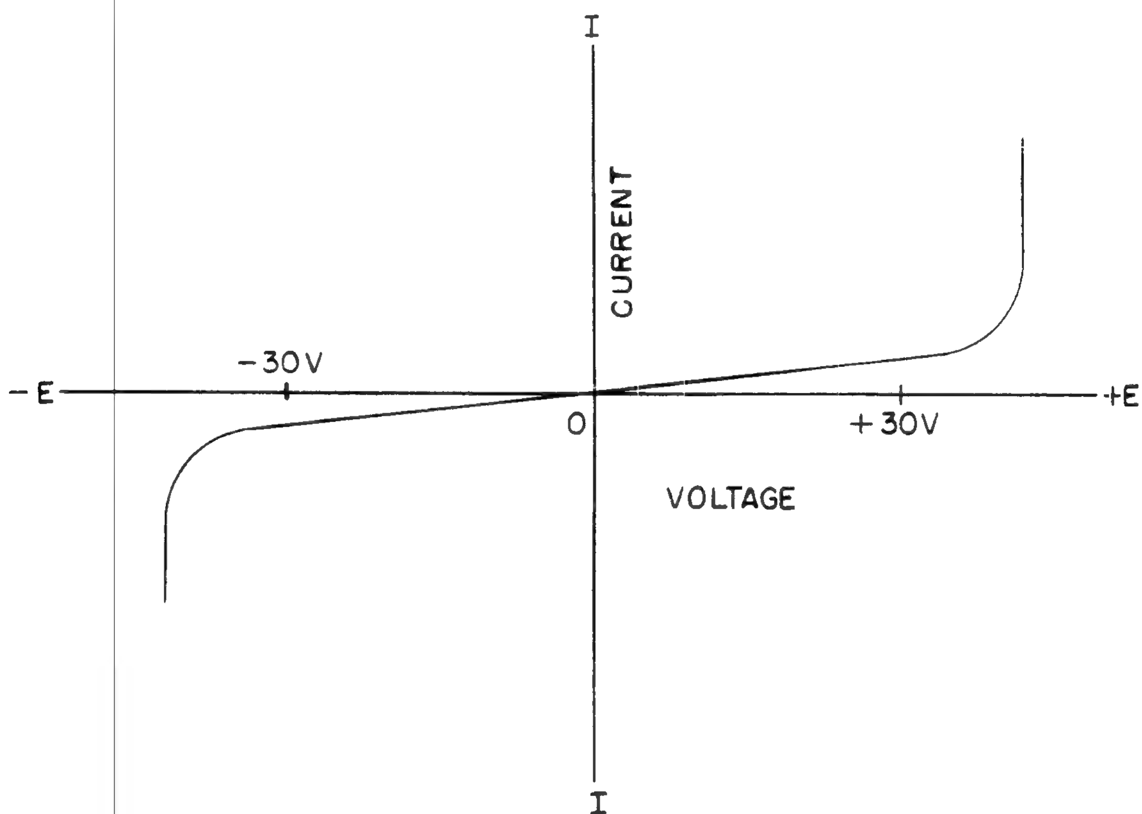


Figure 36. Varistor characteristic curve.

96. USES

The varistor-type limiter is used on most of the DC amplifiers that operate as part of computer servo loops. They start limiting the DC amplifier output voltage at approximately plus and minus 30 volts. The limiting action is not sharp and the threshold may vary with temperature, amount of current flow in the varistor, and construction.

Section V. ORDER LIMITING

97. GENERAL

The order limiting circuit is required because the maximum acceleration order that may be transmitted to the missile must be reduced as the height of the missile above sea level increases. At moderate altitudes above sea level, the missile can execute orders up to 5g acceleration per fin pair. As the altitude increases and the density of the air decreases, larger and larger fin deflections are required to produce the same turning moment on the missile. As a result, the missile develops instabilities when it is ordered to execute large (5g) accelerations at high altitudes. Therefore, it is necessary to insure that, as the missile gains altitude above sea level, the limiting of the fin orders is decreased below the 5g limit established for fin accelerations at moderate altitudes. The decrease in the limiting value as altitude above sea level increases is accomplished by the order limiting circuit.

98. THE ORDER LIMITING CIRCUIT

The order limiting circuit consists of the plus and minus order limiting amplifier circuits, the order limiting limiter, the G_Y limiter, the G_P limiter, and the order limit threshold control (TM 9-5000-26, p 81).

99. FUNCTIONAL OPERATION OF THE ORDER LIMITING CIRCUIT

The fin orders result from voltages produced as outputs by the G_Y and G_P amplifiers. The output voltages are limited by the action of the G_Y and G_P limiters, which are the conventional type discussed in paragraphs 78 through 85. However, these limiter circuits differ from the other diode limiters used in the computer in that they are biased by a variable voltage instead of a fixed voltage. The bias voltage is called the order limiting voltage, and is supplied to the G_Y and G_P limiters as +OL and -OL. The limiter circuit is arranged so that it will limit the output voltages of the G_Y and Gp amplifiers when the positive or negative magnitude of the output voltages exceeds the magnitude of the order limiting voltages. The order limiting voltages are supplied by a circuit

which accepts missile-height data from the missile coordinate converter and develops a positive voltage and a negative voltage which vary with missile altitude.

100. ORDER LIMITING REQUIREMENTS

The present requirements of the order limiting circuit are:

a. To limit the G_Y and G_P outputs to a maximum of 5g's (100 volts) when missile altitude above sea level is 30,000 feet or less.

b. To reduce the limiting value by 1g (20 volts) for each 8,000-foot increase in altitude between 30,000 and 50,000 feet above sea level. (For example, if the missile is 38,000 feet above sea level, the outputs of the G_Y and G_P limiters will be limited when the output exceeds 4g's.)

c. To reduce the limiting value by 1g (20 volts) for each 13,300-foot increase in altitude above 50,000 feet above sea level. (For example, if the missile is 50,000 feet above sea level, the G_Y and G_P orders will be limited when the orders exceed 2.5g's, then if the missile goes from 50,000 feet to 63,300 feet, the 2.5g limiting value will be reduced to 1.5g's.) Since work is in progress to reduce or eliminate, if possible, the missile instabilities resulting from large acceleration orders at high altitudes, the circuit for generating the order limiting function is as flexible as possible. The altitude above sea level at which limiting begins (30,000 feet at the present time) is established by the position of the OL THRESHOLD potentiometer. This potentiometer is geared to a dial that indicates the order limit threshold in feet. The threshold is the height of the missile above the radar site at which the order limit starts reducing the maximum fin orders. This potentiometer also provides a method of introducing the height above sea level of the radar site. The missile-height data obtained from the missile-coordinate converter is height of the missile above the missile-tracking radar. The computer does not know the height of the missile above sea level. The difference between radar altitude and the absolute altitude of the missile can be corrected by using the OL THRESHOLD potentiometer. For example, suppose that the reduction of order limit from ±5g should begin at 30,000 feet above sea level, and that the radar site is 4,000 feet above sea level. In this case, the OL THRESHOLD potentiometer should be set at 26,000 feet. The range of the OL THRESHOLD potentiometer extends from 0 to 60,000 feet. This range is large enough that, in case the missile instabilities are eliminated entirely, it will be possible to set the threshold to a value that is higher than any altitude that the missile might reach in actual flight.

Section VI. ORDER LIMITING CIRCUITS

101. GENERAL

The order limiting amplifiers compute the +OL and -OL voltages that are supplied to the G_Y and G_P limiters to establish the thresholds at which the limiting action of the G_Y and G_P limiter occurs. The functional schematic of the order limiting amplifier circuit is shown at 81B10 and 81B11. The two input signals to the order limiting amplifier circuit are the $+H_M$ voltage, supplied by the missile-coordinate converter and the voltage from the OL THRESHOLD potentiometer. The $+H_M$ voltage is a positive voltage representing height of the missile above the missile-tracking radar at a scale factor of 1 millivolt per yard. The voltage tapped off the OL THRESHOLD potentiometer is a negative voltage representing that height of the missile above the missile-tracking radar at which it is desired to start to decrease the +5g or -5g order limit. The scale factor of this voltage is also 1 millivolt per yard. These two input signals are applied to the +OL amplifier through two 1-megohm input resistors in the +OL input network, which also contains a 1-megohm feedback resistor. Until the missile reaches a height equal to the OL THRESHOLD potentiometer setting, the sum of the two input voltages will be negative.

102. THRESHOLD CONDITION

At the threshold value, the sum input voltage will be zero, and after the missile height has passed the threshold, the sum input voltage will be positive. In analyzing the operation of the +OL circuit, it is best to start with the condition at the threshold value, i.e., when the sum of the $+H_M$ and the input from the OL THRESHOLD potentiometer is zero. In this condition, the +OL voltage should still represent 5g's. Since the scale factor of the +OL voltage must be 20 volts per g, this being the scale factor of fin order voltages G_Y and G_P, it follows that the +OL amplifier should have an output voltage equal to +100 volts in the threshold condition. This output value is obtained when the sum of the inputs is zero, because of the -250-volt bias applied to resistor R154. As in all other computer amplifiers, the +OL amplifier keeps the summing point virtually at ground potential. Since voltages at input terminals 3 and 4 of the +OL network add up to zero, the voltage at feedback terminal 2 must also be zero to satisfy the zero-offset condition. When this is the case, no current will be flowing through the grounded resistor, R153. Resistors R154 and R155 then form a voltage divider between the -250-volt bias and the +OL output voltage. If the junction of these two resistors is at zero potential, as it has to be in the threshold condition, there must be a 250-volt drop across R154. Therefore, the current through R154 is approximately 1 milliampere. Since no current is flowing through the feedback resistor and none through R153, the same current must be flowing also through the 100,000-ohm resistor, R155. Therefore, a 100-volt

drop exists across resistor R155. Consequently, in the threshold condition, the amplifier will operate to establish the required +100-volt output.

103. OPERATION OF THE ORDER LIMITING LIMITER IN THE THRESHOLD CONDITION

Reference to the schematic will show that the order limiting limiter is connected between the input and output terminals of the +OL amplifier. The operation of the diodes in the OL diode panel during the threshold condition will now be discussed. Refer to TM 9-5000-26, page 86. The plate of V3A (pin 7) and the cathode of V3B (pin 5) are connected to the summing point and are at zero potential. (Note that a 6AL5 twin diode is used in this limiter. This is because the stringent back-resistance requirement met by 5755 diode-connected triodes is not necessary in this application.) The voltage at pin 2 (the plate of V3B) is established by the voltage divider formed by resistors R15 and R14. At the threshold condition (+OL is 100 volts), this voltage divider establishes ground potential at the plate of V3. Diode V3B has zero potential across its electrodes and is nonconducting. However, it is on the verge of conduction and starts to conduct as soon as the amplifier output voltage rises above +100 volts. Voltage divider R16 and R13, between -250 volts and +100 volts (the order limiting threshold), establishes +41 volts at the cathode of V3A, and the diode cuts off.

104. GAIN OF THE +OL AMPLIFIER IN THE THRESHOLD CONDITION

Since the feedback resistor is equal to the input resistors, unity gain would be obtained if the output voltage were fed back directly. However, the feedback voltage is tapped off at the junction of resistors R153, R154, and R155 (81B11,TM 9-5000-26). Thus, the gain of the amplifier will be higher than unity gain, and will be established by the ratio of the output voltage to the voltage tapped off at the junction. To calculate this ratio, it is necessary to take into account the fact that R155 is shunted to ground through R154 and R153 to the -250-volt supply, and is shunted to the virtual ground established at the summing point by the feedback resistor. Therefore, the effective resistance of the lower arm of the voltage divider is 16,900 ohms in parallel with 249,000 ohms and 1 megohm. The equivalent resistance of this parallel combination of resistance is 15,580 ohms. The ratio of the output voltage to the voltage tapped off at the junction of resistors R153, R154, and R155 is $(100,000 + 15,580)/15,580 = 7.5$ (effectively) and the +OL amplifier operates with a gain of 7.5. The 1-megohm feedback resistor operating in conjunction with the 7.5/1 dividing network in the feedback circuit has the same effect as direct feedback through a 7.5-megohm feedback resistor.

105. CIRCUIT OPERATION UNDER NONTHRESHOLD CONDITIONS

Suppose H_M is below the threshold value. In this case, the sum of the two input voltages will be negative and the output voltage will rise above +100 volts. The amplifier operates to balance the negative input sum by increasing its positive output. But diode V3B, which was shown to operate at zero plate potential in the threshold condition, conducts as soon as the output voltage rises above the threshold value of +100 volts. The resistance of the diode then becomes negligible in comparison with R14 and there is a direct feedback path through the 100,000-ohm resistor, R14. The gain of the amplifier thus changes abruptly from 7.5 to a value slightly less than 0.1. (The effective feedback resistance becomes slightly less than one-tenth the value of the input resistors.) Suppose the missile is 12,000 feet above the MTR. The voltage at terminal 3 of the +OL input network will be +4 volts. Suppose the MTR is 3,000 feet above sea level. The OL THRESHOLD potentiometer will be set at 27,000 feet. Therefore, the potential at terminal 4 will be -9 volts. The total input voltage is then -5 volts. This input voltage will produce an output voltage of 100 + (0.1 x 5), or 100.5 volts. If the missile were on the launcher, the output voltage (+OL) would be slightly less than 101 volts. For all practical purposes, it is correct to state that output voltage remains constant at +100 volts (+5g order limit) as long as H_M is between zero and the threshold value. It is held at +100 volts by the limiting action of V3B. When H_M rises above the threshold value, the sum of the two input voltages becomes positive. The amplifier balances the positive input sum by decreasing the +OL output. Refer to the OL limiter. As soon as the +OL output decreases below 100 volts, the plate of V3B becomes negative and both sections of V3 are nonconducting. The cathode of diode V3A becomes less negative than the 41-volt threshold value, and V3A cannot conduct. The +OL amplifier under these conditions will operate at its normal gain of 7.5. Suppose that the missile is 30,000 feet above the MTR and that the MTR is 3,000 feet above sea level. The OL THRESHOLD potentiometer would be set at 27,000 feet. The potential at terminal 3 of the +OL input network is +10 volts, and the potential at terminal 4 of the same input network is -9 volts. The sum of these two input voltages is +1 volt. The +OL voltage will, therefore, be 100 - (1 x 7.5) or 92.5 volts. If the missile altitude were to increase by another 3,000 feet, the potential at terminal 3 would increase by 1 volt and the resultant +OL output would decrease by another 7.5 volts. Since 7.5 volts represents 3/8(g), each increase of 3,000 feet in the missile altitude above the threshold value results in a decrease of 3/8(g) in the OL output. Each increase of 8,000 feet in missile altitude above the threshold value will result in a reduction of the order limiting output by 20 volts, the equivalent of 1g.

106. LIMITING AT ALTITUDES MORE THAN 20,000 FEET ABOVE THRESHOLD

The +OL amplifier continues to operate at a gain of 7.5 until the missile height reaches the threshold limit plus 20,000 feet (50,000 feet at the present time). By that time, a total reduction of 2.5g in the order limiting voltages has occurred. The order limit is down to +2.5g and -2.5g, and the +OL voltage equals +50 volts. Refer to the OL limiter circuit again. With this value of +OL voltage, the voltage divider formed by resistors R16 and R13 establishes zero potential at the cathode of V3A. As soon as the missile height exceeds threshold height plus 20,000 feet, the +OL voltage drops below +50 volts, and diode V3A passes current. This establishes an additional feedback path which reduces the gain of the +OL amplifier. The feedback potential appears at the junction of R13, R12, and R16. The ratio between the total feedback available and the actual feedback potential is established by R13 and R16 and is approximately 1.2. The potential at the junction is then applied to the summing point through the 9.5 megohms of resistance presented by R12 and R17. The effect of this arrangement is the same as it would be if direct feedback were used in conjunction with a feedback resistor with a value of 9.5 x 1.2 megohms, or 11.4 megohms. For all practical purposes, in this condition, two feedback paths exist: one with an effective feedback resistance of 7.5 megohms, the other with an effective feedback resistance of 11.4 megohms. These two resistances in parallel have a total equivalent resistance of 4.5 megohms. Consequently, when V3A conducts, the gain of the amplifier drops abruptly from 7.5 to 4.5. When the amplifier operates with a gain of 4.5, a 3,000-foot increase in missile altitude reduces the output voltage by 4.5 volts. Therefore, a 20-volt reduction in the output voltage, corresponding to 1g, results from an increase in missile altitude of:

$$\frac{20}{4.5} \times 3{,}000 \text{ feet} = 13{,}333\ 1/3 \text{ feet},$$

or a nominal value of 13,300 feet. Accordingly, when the missile height increases beyond threshold height plus 20,000 feet, the order limiting voltage is reduced by 20 volts, or 1g, for each 13,300-foot increase in altitude.

107. OL THRESHOLD POTENTIOMETER

Excitation for this potentiometer is -250 volts from the 250-volt regulator. The voltage is reduced to -20 volts by resistor R24, which forms a voltage divider with the winding of potentiometer R23. The -20-volt value corresponds to the extreme threshold setting of 60,000 feet (20,000 yards).

108. -OL AMPLIFIER

The +OL voltage obtained from the +OL amplifier is applied to input terminal 3 of the -OL network (81C10). The network contains a 0.5-megohm input resistor and a 0.5-megohm feedback resistor. Therefore, the -OL amplifier operates with unity gain and simply reverses the polarity of the +OL voltage.

109. G_Y AND G_P LIMITERS

The outputs of the +OL and -OL amplifiers are applied to the G_Y and G_P limiters. Refer to **TM 9-5000-26,** page 88. The G_Y limiter, V2, and the G_P limiter, V3, are diode limiters that operate according to the principles explained in section III. The two sections of dual triode V2, which limits the output of the G_Y amplifier, are connected as diodes. If neither section of V2 is conducting, the G_Y amplifier operates in its normal fashion; that is, with a gain of 100/t. If V2A is conducting, its resistance drops to a low value and 100K resistor R8 shunts the normal feedback path. This drops the amplifier gain from its normal value, 100/t, to slightly less than 0.1. Similarly, if V2B is conducting, the normal feedback path is shunted by the 0.1-megohm resistor, R6, and the amplifier gain is again reduced to just below 0.1. As long as the positive or negative magnitude of the G_Y voltage does not exceed the magnitude of the order limiting voltage, the cathode of V2A will be at a positive potential and the plate of V2B will be at a negative potential. Since the plate of V2A and the cathode of V2B are at the virtual ground potential established at the summing point of the G_Y amplifier, both sections will be cut off. When the G_Y output voltage becomes equal to the +OL voltage, the voltage divider formed by resistors R5 and R6 establishes zero potential at the plate of V2B. If the output voltage increases beyond that, V2B passes a current proportional to the rise of the output voltage above the order limiting voltage. This reduces the gain of the amplifier to a value slightly less than 0.1 and holds the G_Y output at the value of the order limiting voltage. Tube V3 operates in an identical manner.

Section VII. ORDER SHAPING

110. GENERAL

The S_T and S_C signals applied to the fin order solver are error voltages developed in the over-all missile control loop. This loop causes the missile to be positioned in flight so that it will intercept the target. Basically, the control loop operates on the proportional mode of control. This means that the acceleration orders for the missile are made proportional to the error voltages. The response of a proportional controller can be improved by making it error rate

sensitive. Instead of controlling the output member (in this case the missile) in accordance with only the direction and magnitude of the error, the controller also takes into account the rate at which the error is changing. By observing the rate of change of the error, the controller can anticipate future acceleration requirements and make the response more accurate. The technique of adjusting the acceleration of the output member of a control in accordance with the error rate is called lead equalization or derivative control. The term lead equalization comes from the fact that in using lead equalization, a given output of the controller will occur sooner than it will with strict proportional control. The term derivative control arises from the fact that error rates are determined mathematically by taking the derivative of the output with respect to time.

111. EXAMPLE OF STRICT PROPORTIONAL CONTROL

The rudder of a ship if steered according to the strict proportional mode of control is deflected in proportion to the heading error existing at the time. Suppose that the ship is proceeding along the correct course with the rudder undeflected when, because of a current, it starts turning to starboard. As the heading error increases, the rudder turns slowly to port. The starboard drift of the ship is first slowed and then brought to a halt when there is already a considerable heading error. By this time, the rudder has been turned sharply to port and causes the ship to start turning to port toward the correct heading. The ship will gain angular momentum in the process. As it approaches the correct heading, the rudder turns back toward the undeflected position, but the angular momentum built up during the heading correction causes the ship to continue turning to port, and the correct heading is overshot. Then the process repeats in the reverse direction: as the rudder turns slowly to starboard, the ship will overshoot the correct heading several times before the correct heading is reestablished. Obviously, this is not the best method for steering the ship.

112. EXAMPLE OF PROPORTIONAL PLUS DERIVATIVE CONTROL

The steering in the example above can be improved by making it error rate sensitive. Again the ship proceeds along the correct course with undeflected rudder when the current causes it to turn starboard. This time, an increase in the rate of heading error is noted immediately, even before time has passed for the heading error to accrue to an appreciable value. Responding to the error rate, the rudder deflects to port sooner than it would if strict proportional control were used. The starboard momentum of the ship is thus overcome, and the starboard rotation is quickly stopped. As the starboard rotation of the ship becomes very slow, the error rate reduces and the additional rudder deflection dictated by derivative control is negligible, when compared to the rudder deflection called for by strict proportional control. The rudder is then kept deflected to port in proportion to the accrued starboard heading error, but the more

prompt movement of the rudder has kept the total change in the starboard direction to a much smaller value. Proportional control now causes the ship to turn to port. As the ship builds up angular momentum in the port direction, the increasing rate of decrease of the error is noticed by the error rate sensitive device. This causes the rudder to turn back to zero deflection faster. As the ship approaches the correct position, the rudder is deflected very little by proportional control, since the heading error is now small. However, the error rate sensitive device now detects a decreasing rate of error and deflects the rudder starboard before it reaches the correct heading. Thus, the port rotation of the ship can be brought to a halt with little or no overshoot. The rudder has turned first to port and then to starboard as in the strict proportional control illustrated, but the rudder moved sooner than in the pure proportional case. The lead in rudder response considerably reduced the first buildup of the error and the amount of overshoot.

113. CONFLICTING REQUIREMENTS

The preceding discussion illustrates that lead equalization has the advantage of more rapid and more accurate response to changing control requirements. In the example of the ship, the sudden change in the control requirement was caused by a sudden current. Changes in missile control requirements are usually caused by maneuvers of the target. Any acceleration of the target, such as a turn or a dive, makes it necessary to change the course of the missile. The change in the intercept course will be reflected in a more or less sudden increase in the steering error components. Lead equalization makes the missile control loop response very sensitive to such rapid changes in the error voltages. Sensitivity is desirable from the point of view of pursuit, but it has a serious disadvantage. Because the radar tracking of the target and missile is not perfectly smooth, spurious fluctuations will occur in the error signals applied to the fin order solver. These result in the sending of spurious orders to the missile. The noise orders will cause the fins of the missile to flap erratically. Since the flapping motion of the fins will center about the desired fin position, it will usually be averaged out, due to the inertia of the missile,and the course will not be affected. However, the jerky motions of the control fins greatly increase the air resistance and slow the missile down. For this reason, the fin order solver should be as insensitive to noise as possible. Thus, it appears that rapidity of response to target accelerations and insensitivity to noise are two conflicting design requirements.

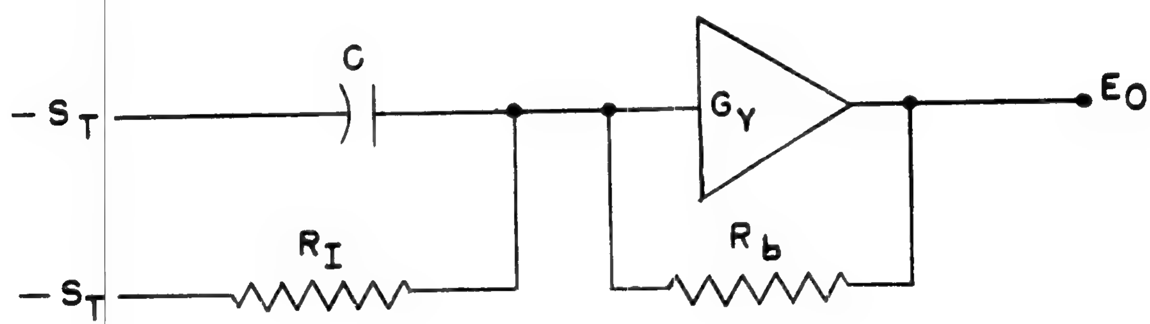
114. COMPROMISE SOLUTION

A compromise is achieved by inserting the lead equalization in steps. In the early stages of the pursuit, when the missile is still far from the target, ample time is available for adjusting the course of the missile. Prompt response to

target acceleration is unessential and lead equalization is not required. As the time before intercept decreases, speed of response becomes more and more important, and lead equalization is switched in when the time to intercept (t) equals 24 seconds, if RADAR CLEARED and ON TRAJECTORY have occurred. (It is not desirable to use lead equalization when the initial-turn section has control of the missile.) In the final phase of the pursuit, rapidity of missile response is of utmost importance. So, for the last 10 seconds before intercept, the lead equalization is doubled with respect to the amount put in at 24 seconds time to intercept. Loss of missile speed because of fin flapping is the lesser of two evils during the final phase. The amount of lead equalization and the optimum time for switching it in are design factors which are not yet completely clarified. If experience with the equipment shows that changes in these design factors would improve performance, these changes can be brought about by minor modifications of the circuit arrangement.

115. SIMPLIFIED CIRCUIT ARRANGEMENT

The addition of derivative control, or lead equalization to proportional control is accomplished by applying each of the S_T and S_C voltages to differentiating networks which feed into the G_Y and G_P input networks along with the normal resistive inputs. The simplest possible circuit arrangement is shown in figure 37.



$$E_O = E_P + E_D$$

$$E_P = S_T \times \frac{R_b}{R_I}$$

$$E_D = \dot{S}_T \times R_b C$$

Figure 37. Simple order-shaping circuit.

In this figure, the voltage that represents $-S_T$ is shown applied to an input resistor, R_I, and an input capacitor, C. Let E_P represent the output of the G_Y amplifier resulting from weighting established by the ratio $R_B:R_I$. Let E_D represent the output of the G_Y amplifier resulting from weighting established by the action of C in conjunction with R_B. Assume that the G_Y amplifier output is fed directly into R_B. (If the reader remembers that the outputs derived in this discussion are multiplied by the factor 100/t, the assumption will be reasonable.) The output voltage of a DC amplifier used as a differentiating circuit is proportional to the rate at which the input is changing, where the weighting factor (constant of proportionality) is given by the expression,

$$R_B \times C. \tag{88}$$

Thus, the voltage, E_D, is obtained from the equation,

$$E_D = (+\dot{S}_T)\ (R_B \times C). \tag{89}$$

The total output voltage of the G_Y amplifier, E_O, is then given by:

$$E_O = E_D + E_P. \tag{90}$$

Since E_O depends upon the time rate of change of $-S_T$, the total output is modified by the manner in which $-S_T$ changes with respect to time. If $-S_T$ is increasing, the magnitude of the G_Y output will be greater than it would be normally, with only a resistive input circuit. If $-S_T$ is decreasing, the magnitude of the G_Y output will be less than it would be if only a resistive input network were used. If $-S_T$ is not changing, the output of the differentiating input network will be zero and the G_Y amplifier will operate in strict proportional control. One disadvantage in this simple network is that the differentiating network as shown will respond to any change in the $-S_T$ input and would therefore respond to changes caused by potentiometer granularity and the fluctuations resulting from antenna tracking of missile and target. These rapid variations must be smoothed out. Smoothing is accomplished by the addition of a resistor in series with the capacitor (fig 38). Resistor R_B will not affect the output except to slow down the rise in the output voltage caused by a rapidly changing input. Rates whose durations are short, compared to the time constant, thus do not affect the output.

116. RESPONSE TO INPUT WHICH CHANGES AT CONSTANT RATE

Consider the response of the order-shaping circuit to an input which changes at a constant rate (ramp function). Figure 39 shows the $-S_T$ voltage increasing in a negative direction at a constant rate. The output, E_P, resulting from this input, is shown in figure 40. The output increases in a positive direction because of the inverting property of the G_Y amplifier. The output, E_D, is shown

in figure 41. Note the effect of the time constant formed by R_S and C. After the exponential rise, voltage E_P is constant, proportional to the rate at which $-S_T$ is changing. The total G_Y output is the sum of E_D and E_P and is shown in figure 42. The dotted line shows the output of the G_Y amplifier without order shaping. At

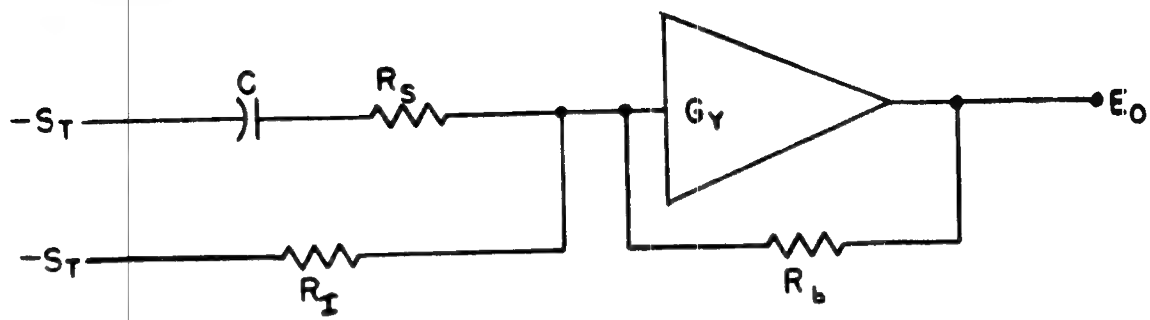


Figure 38. Order-shaping network with data-smoothing resistor.

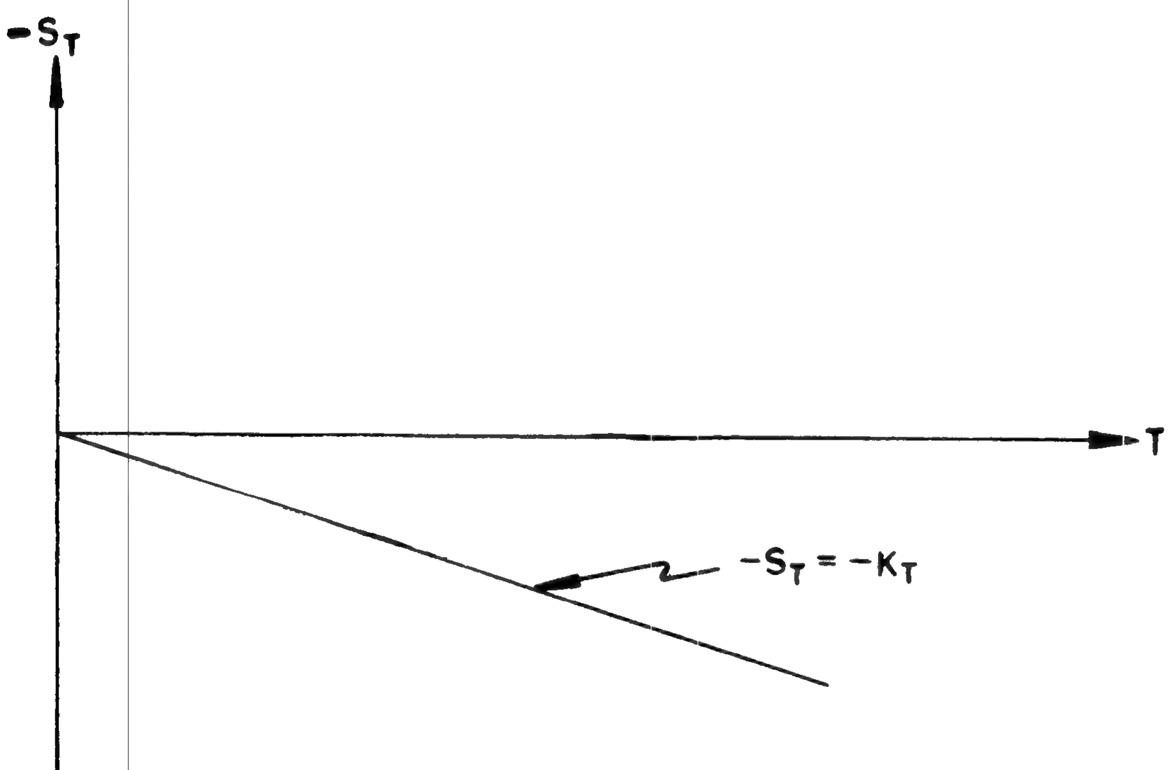


Figure 39. The $-S_T$ voltage as a ramp function input.

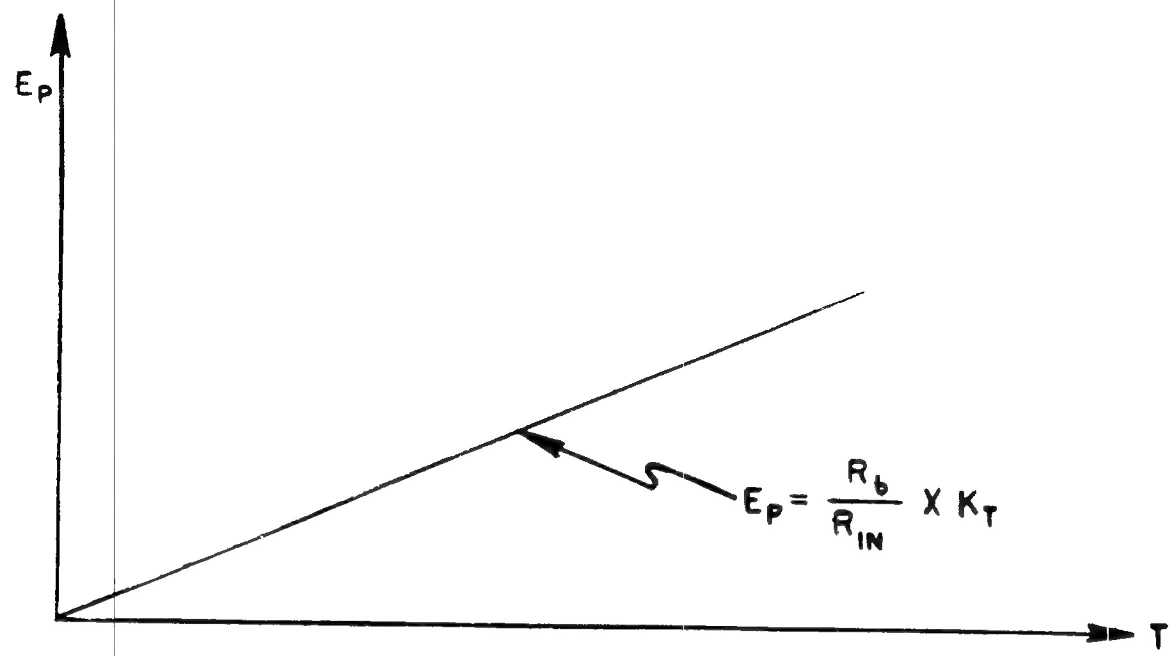


Figure 40. Output of G_Y amplifier without order shaping.

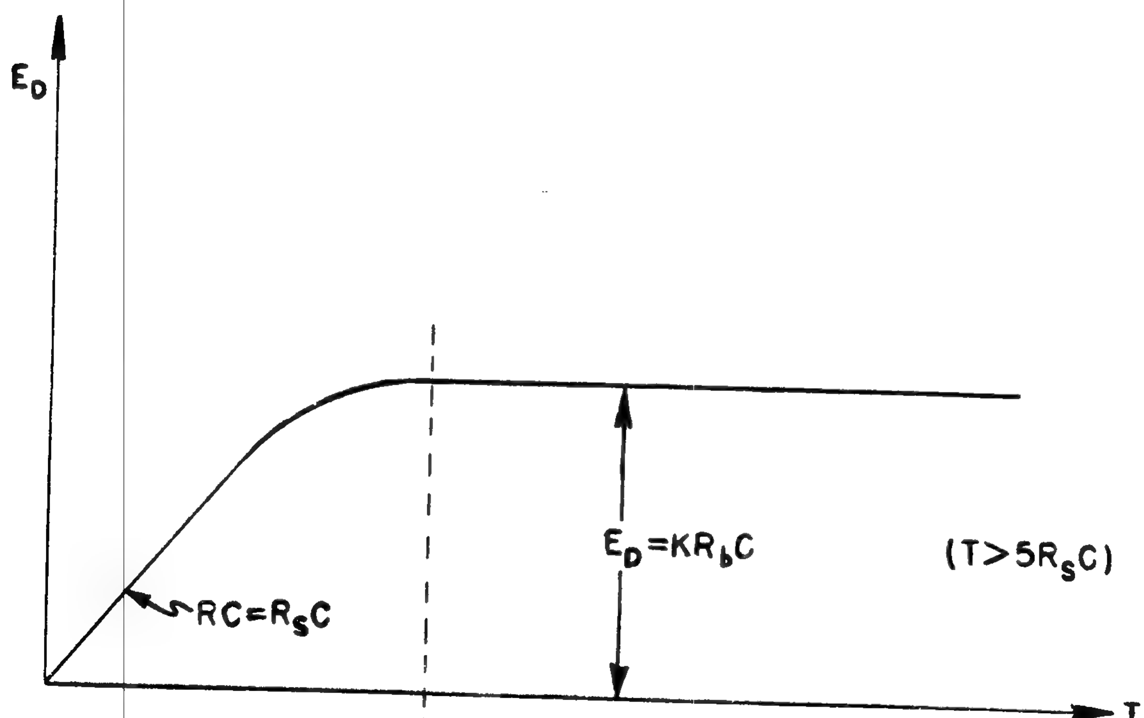


Figure 41. Output of G_Y amplifier resulting from the derivative circuit alone.

some arbitrarily selected instant of time, t_1, the output of the G_Y amplifier without order shaping will be E_1. However, with order shaping, the output, E_1, will be reached at time, t_0, which is earlier than t_1. The amount by which t_0 leads t_1 can be determined from examination of the triangle OAB. The distance between points O and A represent the amount by which t_0 leads t_1. The length of line AB is kR_BC (since E_0 is greater than E_P, by the output of the order-shaping network, which is $R_BC \times (+S_T)$, and $+S_T$ is equal to k, the rate at which $+S_T$ is changing). The rate at which E_0 is rising is also k and is equal to the tangent of the angle AOB. Thus:

$$\tan AOB = \frac{AB}{OA}, \tag{91}$$

$$k = \frac{kR_BC}{OA}. \tag{92}$$

Therefore, the line of line OA is equal to R_BC, and consequently point t_0 is R_EC seconds ahead of point t_1. The significance of this discussion is that voltage E_0 leads voltage E_P (which would be the output of G_Y without order shaping) by a number of seconds equal to R_BC. Order shaping causes the G_Y amplifier output

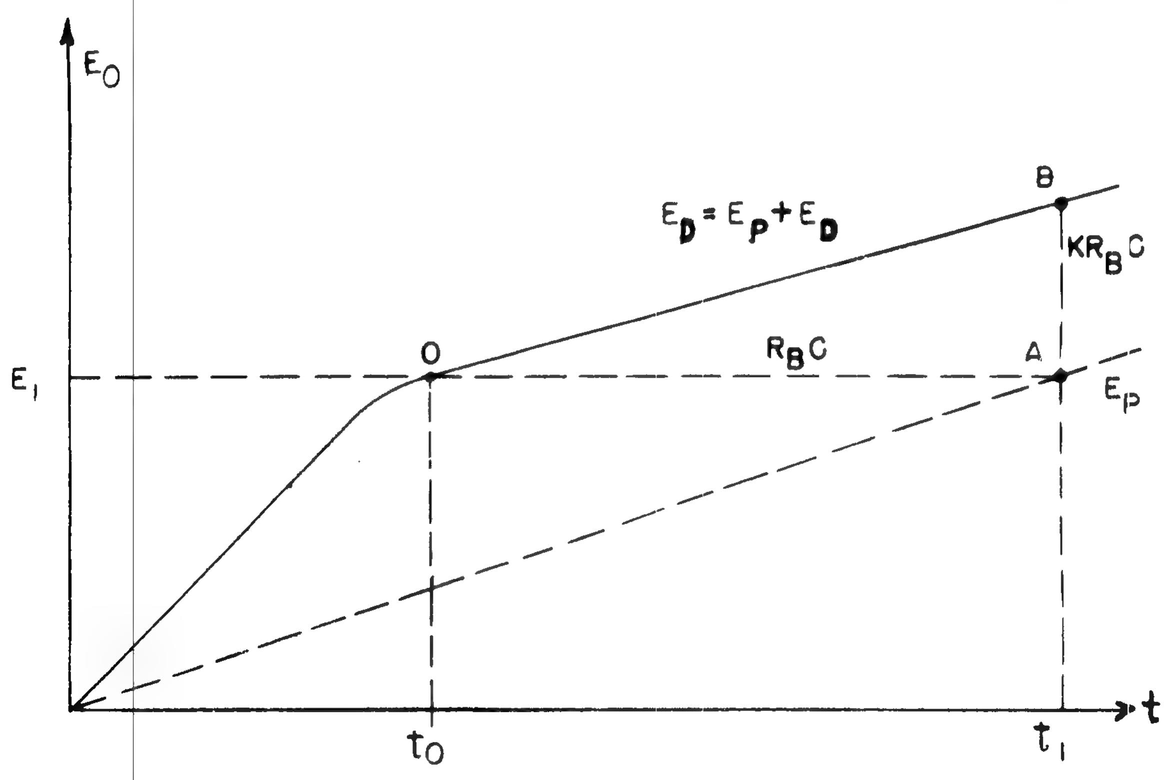


Figure 42. G_Y output resulting from order shaping (ramp function input).

to lead its normal output by R_BC seconds. This value, R_BC, is a measure of the amount of lead equalization introduced. At a time to intercept of 24 seconds, the amount of lead equalization put in the computer is 1 second. When t is 10 seconds, this amount is doubled, so that the lead equalization is 2 seconds. The 1-second lead equalization is called half order shaping and 2-second lead equalization is called full order shaping. Although the special case of a constantly changing input has been used here for simplification, the fact that the output with order shaping leads the output without order shaping by R_BC seconds holds true for any input function except a zero input.

117. DETERMINATION OF THE AMOUNT OF LEAD EQUALIZATION

A simple circuit for establishing 1-second lead equalization is shown in figure 43. Capacitor C is 1μfd, R_S is 0.62 megohm, and R_B is 1 megohm. A simple circuit for obtaining 2-second lead equalization is shown in figure 44. By paralleling one R-C network with another, one which has identical elements, an R_BC factor of 2 is obtained, and the smoothing time constant is kept the same. The next step in building up the circuit is to provide a means of switching from 1-second lead equalization to 2-second lead equalization. Figure 45 shows the R_S resistor and the summing point. The other terminal of the relay is grounded. Since the summing point is at virtual ground, no transient will occur during a change in charge on C as the circuit is switched from 1-second to 2-second operation. Note in both figures 44 and 45 that each capacitor carries the same voltage, but that one-half of the total current resulting from the input flows from each capacitor. Because of these conditions, the circuit can be improved by using a single 2μfd capacitor in place of the two 1μfd capacitors, without affecting the operation of the circuit. This final arrangement is shown in figure 46. During half overshaping, only one-half of the capacitor is used, since half of the total current flows directly to ground.

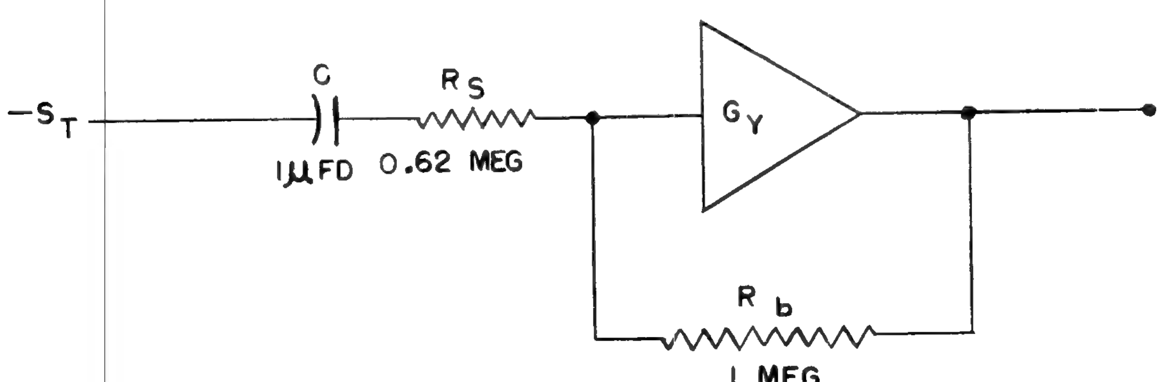


Figure 43. Simple 1-second lead equalization network.

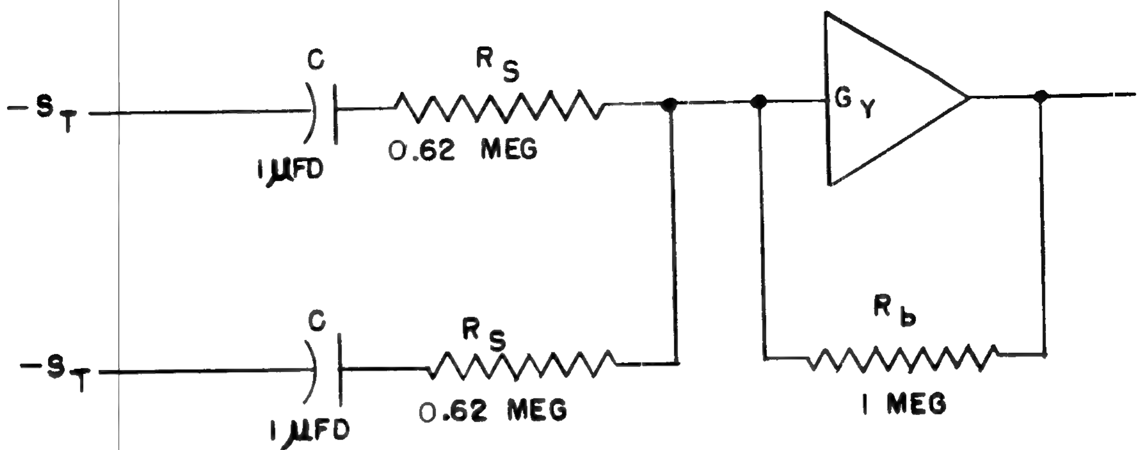


Figure 44. Simple 2-second lead equalization network.

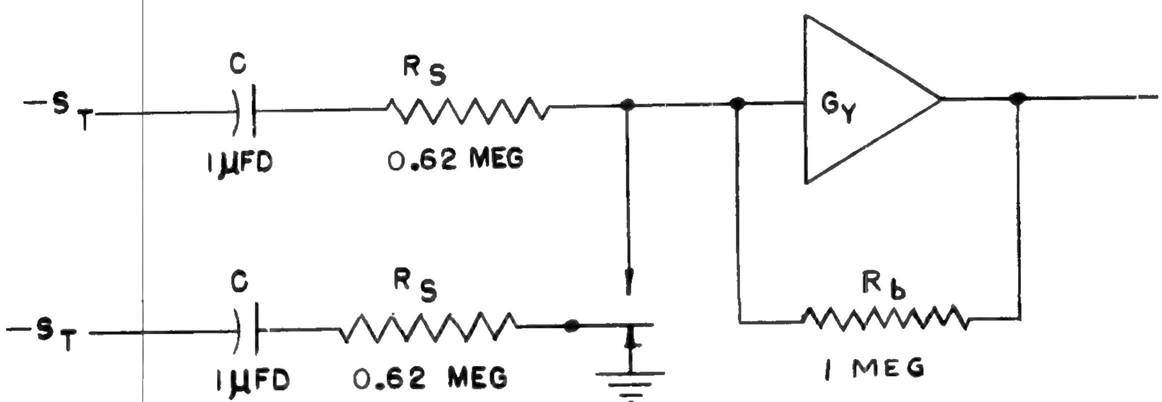


Figure 45. Simple switching arrangement.

118. THE ORDER-SHAPING NETWORK

Since the operation of order shaping is identical in both channels, only one channel will be discussed in detail. The G_Y channel and the $-S_T$ input will be discussed in detail. The functional diagram of the order-shaping network is shown at 81A9 . Capacitor C377 is used in this channel. It is connected between terminals 1 and 6 of P1 on the G_Y order-shaping panel. The $-S_T$ voltage brought into the order-shaping network panel is shown in TM 9-5000-26, page 89. Relay K1 (89D5) is energized whenever t is 24 seconds and RADAR CLEARED and ON TRAJECTORY have occurred. Before the energizing of K1, no order shaping takes place, since the path from the $-S_T$ input to C377

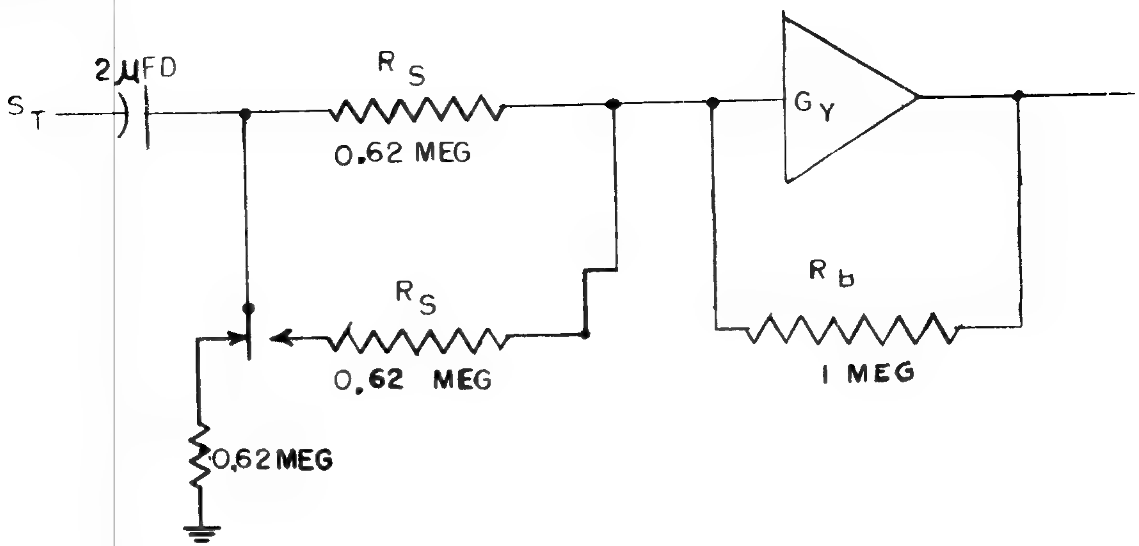


Figure 46. Nike I computer order-shaping network.

is broken and the order-shaping network is out of the amplifier circuit. When K1 is energized, K2 remains deenergized. The path for current flow resulting from the $-S_T$ input is from C377 to the junction of R5 and R6. At this point, the current splits and one-half is grounded through R6 and terminals 3 and 4 of K2. The other half of the current is applied to the summing point (P2) through R5. The parallel combination of R5 and R6 in conjunction with C377 establishes the time constant of 0.62 second. This means that the circuit responds fully to a rate only after it has persisted for at least 2 seconds. Rates lasting for less than 0.2 second are disregarded. Between these two limits, a rate is weighted in accordance with how long it has existed. At a time to intercept of 10 seconds, relay K2 is energized. In this condition, capacitor C377 is coupled to the input grid of the G_Y amplifier (through P2) through resistors R5 and R6, which are now in parallel. Again, the switching proceeds without transients, since the resistance from the capacitor to ground remains unchanged. The connection now is equivalent to that shown in figure 44. Each of the two parallel resistance-capacitance branches provides a 1-second lead, giving a total lead of 2 seconds. Each branch operates with its own time constant, equal to 0.62 second, so that the over-all effect is that of a 2-second lead with a 0.62-second time constant. Relay K1 is energized by a cam-operated switch located in the time-to-intercept servo if initial-turn relay K124 is deenergized. Relay K2 is also energized by a cam-operated switch in the time-to-intercept servo.

CHAPTER 4

MISSILE-AWAY, 7g DIVE ORDER, AND ON-TRAJECTORY CIRCUITS AND COMPUTER MODIFICATIONS

Section I. MISSILE-AWAY CIRCUIT

119. GENERAL

The missile-away circuit detects missile lift-off. The signal must be received before the computer can continue its normal operational sequence.

120. COMPONENTS

The missile-away circuit consists of the following components:

a. The $-H_M$ amplifier, which uses a capacitive input and a special feedback network. This amplifier detects the change in missile altitude as the missile leaves the ground, and causes relay K1 to energize.

b. Five relays, MA K1, MAL K2, K5, K7, and K59, which accomplish the following operations.

(1) Establish locking circuits that hold the missile-away locking relays energized until the missile bursts or is lost.

(2) Changes the LAUNCH indicators on the battery control console, target-tracking radar console, and missile-tracking radar console from amber to green.

(3) Send the MISSILE AWAY signal to the event recorder.

(4) Remove a relay ground so that the dead-time unit can reset itself when it reaches 7 seconds.

(5) Disable the missile-reject circuit.

(6) Enable the missile differentiators.

(7) Activate a delay timer to provide the time delay, MA + 4.5 seconds.

(8) Close a circuit which permits a ground to be applied to the burst enable relay at the proper time.

(9) Switch the $-H_M$ amplifier from the operation of detecting MISSILE AWAY to that of supplying $-H_M$ to the vertical plotting board, the $\dot{H}_M$ differentiator, and the driven shield of the data transmission cable.

(10) Illuminate the MISSILE light on the horizontal plotting board.

(11) Switch the input data received by the plotting boards to missile and target present position.

(12) Disable the time slew circuit.

(13) Connect $+R_M$ data to the initial turn section of the computer.

121. SIMPLIFIED FUNCTIONAL OPERATION (fig 47)

The amplitude and frequency content of the signal voltage applied to the missile away circuit permits the use of a DC amplifier. By using the $-H_M$ amplifier for this purpose the necessity for an additional DC amplifier is avoided, since the $-H_M$ datum is not required until after MISSILE AWAY. The gain of the DC amplifier, when used to detect missile away is approximately 400. During an engagement the COMPUTER CONDITION switch is set in the ACTION position, and action relay K16 is energized. Initially ground is applied to the $-H_M$ amplifier input network through a contact of the deenergized fire relay K3 and the $+H_M$ datum is not applied to the $-H_M$ amplifier. Capacitor C59 is charged through 100-ohm resistor R119 to a voltage representing the altitude of the individual launcher to be used. This charge on C59 makes possible the operation of the missile-away circuit without being affected by the various altitude differences of the launcher. When fire relay K3 is energized, the ground connection is removed from R119, and any change in the $+H_M$ data will develop an input voltage to the $-H_M$ amplifier through C59. This input voltage will be proportional to the rate of change of $+H_M$ datum. As the missile accelerates upward, the rate of change of $+H_M$ increases. When the rate of change is great enough to cause the output voltage from the $-H_M$ amplifier to reach a level of -22.5 to -27 volts, missile-away relay K1 will energize. This should occur slightly less than 1 second after lift-off. When K1 is energized, its contacts provide a ground through contact 2 of K3 to relays K2 and K5. Relay K5 completes a holding circuit for both K2 and itself. Relay K3 remains energized until the missile bursts or is lost. When K2 is energized, it closes a contact which energizes the MAL 2 relay, K59. Relay K59 places a short across C59 and across K1, deenergizing K1 and allowing the $-H_M$ amplifier to revert to its normal operation of supplying $-H_M$ datum. Relay K59 also places R91 in parallel with R92 in the feedback circuit of the $-H_M$ amplifier, reducing the gain to 1. The feedback capacitor in the input network and C93 are for data smoothing to prevent K1 from being energized by erratic voltage changes. These capacitors help to establish the desired frequency response of the amplifier. Before action relay K16 is

energized, a ground is applied to K59, energizing it and allowing the $-H_M$ amplifier to perform its normal function. Therefore, the missile-away circuit is operative only when the computer is in the action status and before MISSILE AWAY has been detected.

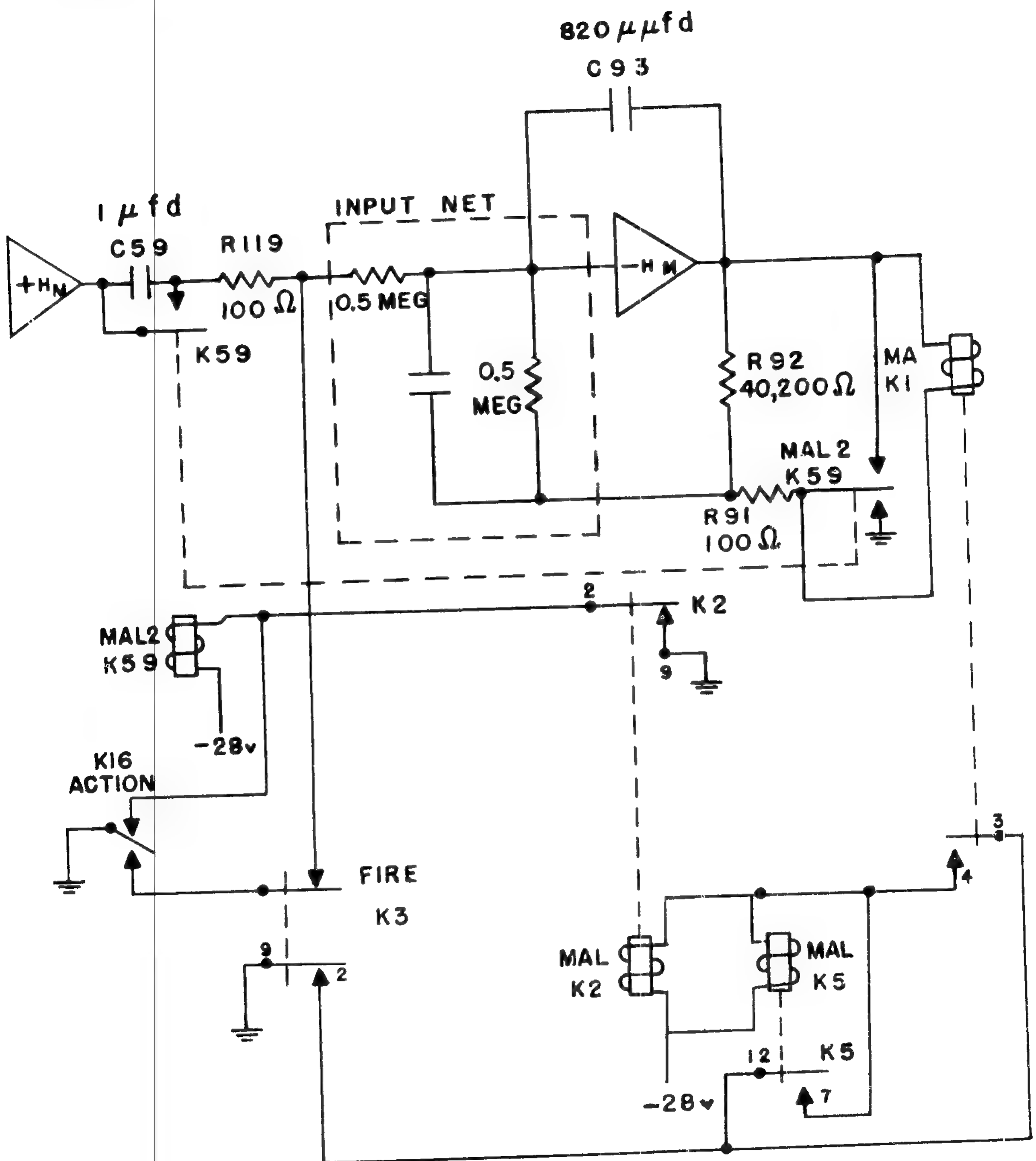


Figure 47. Missile-away circuit, functional schematic.

122. DETAILED FUNCTIONAL OPERATION
(TM 9-5000-26)

Refer to 108A1. The $-H_M$ amplifier is part of the missile coordinate converter. When K59 is deenergized, the circuit is established for missile-away detection. In this condition, neglecting the capacitor in the feedback circuit, the gain of the amplifier can be determined by the following method:

$$\text{Gain} = \frac{R_B}{R_1} \times \frac{R_1 + R_2}{R_2}, \tag{93}$$

thus:

$$\text{Gain} = \frac{500,000}{500,000} \times \frac{40,200 + 100}{100} = 403. \tag{94}$$

However, when considering the capacitance in the feedback circuit, the gain of the amplifier reaches a maximum of 400 between the frequencies of 0.55 cycle per second and 1 cycle per second. Relay K1 is a 4,500-ohm relay, which operates on 5 to 6 milliamperes. To energize K1, an applied voltage of -22.5 to -27 volts is required. This output will be attained when the missile has reached a point approximately 134 yards above the launcher at approximately 1 second after lift-off. The average time of 0.85 second is not critical and will vary; therefore, the time of 1 second after launch will be used in this discussion. At 108C1 a contact of K5 is shown which energizes the missile-away locking relay (MAL 3), K7. Contacts of K7 are shown at 145C8 . These contacts control the missile indicator lights on the horizontal plotting board. The lights identify the pen that is plotting missile data. Other contacts of K7, shown at 106D6, disable the time slew circuit between missile away and burst. At 108C2 is shown a contact of K2, which energizes the relays in the missile differentiator networks, allowing missile velocity data to be produced. At 108D1 is shown a contact of K5 that controls the energizing of the launch relay K8 on the tactical signal panel (battery control console), and supplies a ground to the event recorder. Relay K8 controls the switching of the LAUNCH indicators from amber to green. The LAUNCH indicators are located on the tactical signal panel and on the signal panels at the MTR and TTR consoles. Upon application of the ground connection, the event recorder will plot the time of MISSILE AWAY. At 108A4 is shown a contact of K2 that removes ground from the 4.5-second delay timer, which prevents application of the 7g dive and initial turn orders to the missile until missile boost and roll stabilization have occurred. At 107C13 is shown a contact of K5 that opens one of the two ground connections to the dead-time unit clutch coil. This ground connection energizes the clutch coil at FIRE, causing the dead-time unit gearing to be connected to the dead-time motor. When this starting ground connection is broken, the dead-time unit is being prepared for reset action, which takes place after FIRE + 7 seconds, when the second ground is removed from the clutch coil

by cam-operated microswitch S1. At 107C12 is illustrated a contact of K5 that opens the missile reject circuit, and prevents a reject signal at FIRE + 5 seconds. When the contact of K2 (109A3) closes, ground is connected to the burst enable circuit. However, the burst circuit is not enabled at this time. When the contacts of K5 shown at 98A9 close, $+R_M$ data are applied to the initial turn circuit. At 146A1 are shown contacts of K5 that energize the missile plot relays, allowing missile data to be plotted on both the vertical and horizontal plotting boards.

Section II. 7g DIVE ORDER CIRCUIT

123. GENERAL

The 7g dive order circuit develops and sends orders to the missile at MA + 4, causing the missile to dive in the direction of the predicted intercept point at a maximum allowable rate of acceleration, thus ringing the missile rapidly on trajectory.

124. COMPONENTS

The 7g dive order circuit consists of the following components in a special combination.

a. The -t- and +t-amplifiers. These amplifiers produce a voltage proportional to time that is applied to the fin order solver to form the 7g dive order.

b. NOT ON TRAJECTORY relay K8, and OTL relay K32. These relays switch the 7g dive order out of the fin order solver after the missile is on trajectory.

c. The OT amplifier. This amplifier operates the NOT relay K8.

d. The fin order solver. This unit forms the constant 7g order from the voltage applied to it from the +t-amplifier.

125. CIRCUIT ANALYSIS (fig 48)

Before roll stabilization, the time servo runctions as the time-of-flight predictor. At MA + 4, steer relay K79 is energized, causing the second-per-second bias network to control the time servo which then functions as a time-to-intercept servo. The predicted time-of-flight solution from the prelaunch computer is decreased at a second-per-second rate. This action continues until ON TRAJECTORY, when OTL relay K32 is energized. Before K32 is energized, an input

voltage from the +t-amplifier is applied to both the G_Y and G_P amplifiers in the fin order solver, it is a positive d-c voltage of a magnitude that varies directly with t. The scale factor of the -t-voltage is 1 volt per second, and is originally derived from potentiometer cards in the time servo, which can be set to represent t at a maximum of 100 seconds. Supplying this voltage to the fin order solver results in a constant output voltage of -100 volts from both the G_Y and G_P amplifiers. Since the gain of both amplifiers varies inversely with t, it is necessary that the input voltage vary directly with t to maintain a constant output voltage. The circuit shown in figure 48 shows that the following is a true expression of the output voltage for either the G_Y or the G_P amplifier:

$$-E_{out} = \frac{t}{100 \text{ seconds}} \times 100 \text{ volts} \times \frac{100 \text{ seconds}}{t} \times \frac{R_B}{R_{in}}, \quad (95)$$

or

$$E_{out} = \frac{-t}{t} \times 100 \text{ volts} = -100 \text{ volts}. \quad (96)$$

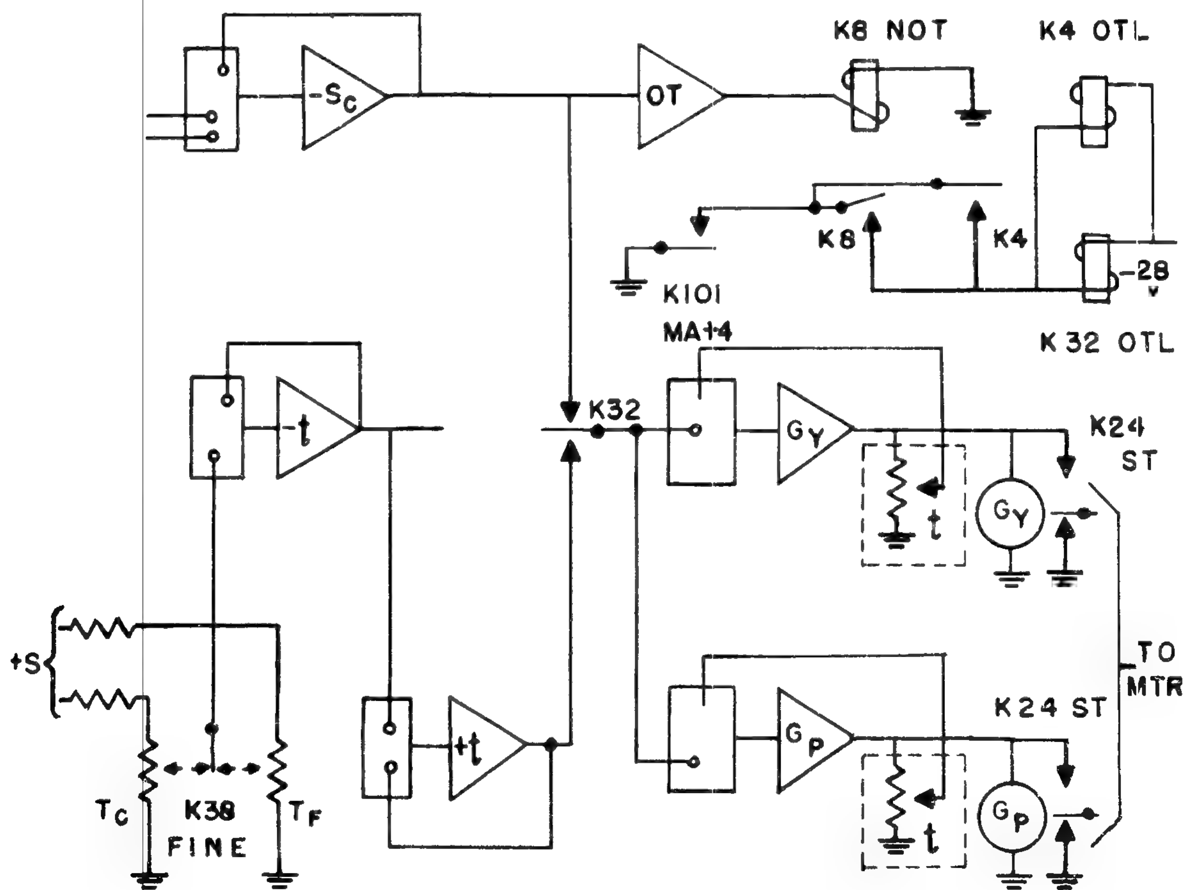


Figure 48. 7g dive order circuit.

When both amplifiers have an output of -100 volts, a 5g dive order is sent to each fin pair of the missile. This results in the maximum 7g dive. The dive order cannot be sent to the missile until steer relay K24 is energized. This occurs at MA + 4. When the missile comes on trajectory, OTL relay K32 energizes, removing the input to the fin order solver from the +t-amplifier.

Section III. ON-TRAJECTORY CIRCUIT

126. GENERAL

The on-trajectory circuit determines when the missile, in the course of its 7g dive, has crossed the proper trajectory line to the target so that the dive order may be removed. The circuit does this by monitoring the output of the $-S_C$ amplifier to determine when the steering error along the climb axis first goes positive. When the climb steering error first goes positive, the missile has just passed through the proper trajectory line and the 7g dive order should be removed.

127. DETAILED CIRCUIT DISCUSSION (TM 9-5000-26, pages 79 and 108)

In the computer, the OT amplifier monitors the S_C signal at the output of the $-S_C$ amplifier. When the missile is executing the dive order, the output of the $-S_C$ amplifier, is a positive voltage. Consequently, the OT amplifier output voltage is negative. The OT diode limiter circuit limits the output of the OT amplifier at -50 and zero volts, a negative voltage at the output of the OT amplifier draws current through NOT ON TRAJECTORY relay K8, keeping the relay energized. As the missile dives toward the proper trajectory, the output of the $-S_C$ amplifier drops toward zero. When this output reaches zero the output of the OT amplifier changes from -50 volts to zero deenergizing the NOT relay K8, which indicates that the missile is "on trajectory."

128. RELAY CIRCUIT OPERATION (TM 9-5000-26, p 108)

When NOT K8 deenergizes, contacts 3 and 1 close, and the on trajectory locking (OTL) relays K4 and K32 are energized through a ground circuit set up by the closed contacts 4 and 5 of MA + 4, relay K101. When OTL K4 energizes, contacts 2 and 3 close, forming a holding circuit around NOT K8. Thus, the OTL relays maintain the on-trajectory condition throughout the rest of the flight. Contacts 4 and 6 of OTL K4 open to remove one of the ground paths from IT relays K124 and K125. The IT relays will deenergize if the RADAR CLEARED signal has been received. If the RADAR CLEARED signal has not been received, the gain of the $-S_T$ amplifier is modified for initial turn orders by removing a ground in the feedback path when OTL K32 contacts 11 and 6 open. Contacts 4

and 5 of OTL K4 close to enable the dither oscillator in the tracking radars. If the RADAR CLEARED signal has been received, OTL relay K32 makes the final transition in the steering section of the computer. When contacts 4 and 10 close, the voltage representing the steering error along missile velocity axis S_V is applied to the time-to-intercept servo. The S_V voltage is an indication of the error in the time solution and is used to modify the second-per-second clock-down of the servo. To counteract the force of gravity, the missile is required to fly a $\frac{1}{2}$g lift trajectory. When contacts 1 and 9 of OTL K32 open, a bias voltage is fed to the $-S_H$ network to give this trajectory. At on trajectory, the 7g dive order is removed and the steering error along the climb axis S_C is connected to the fin order solver by OTL relay K32 contact 12 transferring from contact 8 to contact 7. One additional method of obtaining the ON TRAJECTORY signal is available in the computer. For short times to intercept, it is desirable that the system be placed immediately in the steering configuration. To facilitate this, the t = 10 sec switch in the time servo energizes t = 10 sec relay K34 (109A1). Contacts 2 and 3 of this relay close and apply a ground to OTL relays K32 and K4, forcing the ON TRAJECTORY signal to be given. Under these circumstances, the dive order is initiated by the steering section of the computer and is variable.

Section IV. COMPUTER MODIFICATION

129. GENERAL

In the past, considerable difficulty has been experienced in system operation during the "end game" (the last four or five seconds of missile flight) because of overloading the G_Y and G_P amplifiers. This overloading has resulted from several sources, from "singing" (low-frequency oscillations resulting from noise), from the altitude biasing requirement, and from the inability of the system to follow end game maneuvers of the target because of system time lag. Modifications have been proposed to eliminate these difficulties.

130. SECOND DERIVATIVE NETWORKS

It is planned that a differentiating circuit will be placed at the input to the S_X, S_Y, and S_H amplifiers, which would have target velocities as its input and would give outputs proportional to target accelerations. This circuit would permit the missile to follow maneuvers of the target more easily, since the missile would in effect lead the target as it changed course. Because of this leading of the target by the missile, the gain of the G_Y and G_P amplifiers may be reduced during the end game, reducing the effect of singing. This modification also has the effect of permitting the missile to follow end game maneuvers more easily, since it permits prediction of target position to some extent.

131. ELIMINATION OF 24-SECOND AND 10-SECOND ORDER SHAPING

The present Nike I computer increases the gain of the servo loop during the final phases of missile flight in an attempt to make the system more responsive to target maneuvering. This is accomplished by using order-shaping networks discussed in paragraphs 110 through 118. This increases the gain of the circuit but also makes it more subject to singing. Since the use of second derivative prediction obviates the need for these circuits, they will be replaced by an order-shaping circuit of lesser gain which will continuously apply order-shaping. This will greatly reduce the noise level in the steering order circuits.

132. CHANGE IN GLIDE BIAS

Experiments show that the production of a maximum positive order in the fin order solver is, in many cases, a direct result of the necessity for the system to maintain a $\frac{1}{2}$g glide bias on the missile. See paragraph 44c. To correct this difficulty, the biasing input to the S_H amplifier will be changed to add a super-elevation equivalent to the distance the missile will fall in 10 seconds under the acceleration of gravity. With this modification, all biasing will be removed at I - 10 seconds and the missile will be permitted to follow a ballistic trajectory to the target.

APPENDIX I. STUDY QUESTIONS

1. Study questions for chapter 1.

a. Name the inputs to the steering section of the computer.

b. What data does the steering error solver compare to determine the steering errors?

c. Name the inputs to the steering error converter.

d. What velocity components are used to determine the climb angle?

e. Define the turn angle of the missile.

f. Name the outputs of the steering section.

2. Study questions for chapter 2.

a. What is the purpose of the missile rate converter?

b. Using the following values, calculate the value of the components of missile velocity in gyro coordinates $\dot{X}_{GM}$ and $\dot{Y}_{GM}$.

$\dot{X}_M$ = 400 yd/sec $\qquad$ $\dot{Y}_M$ = 100 yd/sec

c. What are the inputs to the CA servo?

d. Using the following values, calculate the value of the climb angle.

$\dot{H}_M$ = 100 yd/sec $\qquad$ $\dot{Y}_{GM}$ = 100 yd/sec

e. What is the purpose of the geometric gain potentiometer in the feedback path of the CA servo?

f. What are the inputs to the TA servo?

g. Calculate the turn angle if: $\dot{X}_{GM}$ = 500 yd/sec; $\dot{Y}_{GM}$ = 400 yd/sec; and $\dot{H}_M$ = 300 yd/sec.

h. What is the settling characteristic of the missile differentiator?

i. Why are radar-to-radar parallax data necessary?

j. What is the maximum setting that may be made on the radar-to-radar parallax dials?

k. What do the voltage outputs of the closing speed solver represent before t = 0.25 second?

l. Given: X_T = 50,000 yards west, X_M = 21,100 yards west, X_R = 100 yards east, t = 60 seconds. Solve for the ideal closing velocity in the X-coordinate.

m. In the question above, what is the voltage output of $\frac{X}{t}$ amplifier?

n. Refer to $\frac{X}{t}$ amplifier (75A1). Why does switching of feedback resistors occur when relay K1 FINE (75A2) becomes energized?

o. What is the purpose of the 500.5-ohm resistor associated with potentiometer T_F - 10 (75B4)?

p. At what time to intercept does relay K4 (75B2) become energized?

q. At what time to intercept does relay K1 (75B2) become energized?

r. What is the purpose of the steering error solver?

s. What are the scale factors of the inputs to the steering error solver?

t. Given the following quantities, solve for S_X.

X_T is 200 yd/sec (target traveling west),

X_M is 600 yd/sec (missile traveling west),

$\frac{X}{t}$ is -600 yd/sec.

u. In the question above, what is the voltage output of the $-S_X$ amplifier?

v. In the equation $S_H = H + (\frac{1}{4} + \frac{1}{6})\,gt$, what do the quantities $(\frac{1}{4})gt$ and $(\frac{1}{6})gt$ accomplish?

w. What is the purpose of the steering error converter?

x. What are the various transformations that are accomplished by the steering error converter?

y. What are the equations for S_{GX} and S_{GY}?

z. What does S_C represent?

aa. What is the scale factor of the input at terminal 6 of the $-S_H$ input network?

ab. Name the inputs to the fin order solver. Consider only steering error components.

ac. In what planes are the velocity steering errors S_T and S_C?

ad. Why are the steering orders increased by a constant factor of $\frac{3}{2}$?

ae. Suppose S_C = -400 yd/sec, S_T = +200 yd/sec, and t = 40 seconds. Solve for G_Y and G_P.

af. Substitute the proper voltages for S_C and S_T in question 2ae and again solve for G_Y and G_P.

ag. In question 2ae, what action would the missile take in responding to the resulting orders?

ah. What do contacts 6 and 11 of K32 (79B4) accomplish at ON TRAJECTORY?

ai. When does relay K126 (79B6) energize?

aj. What are the maximum possible outputs from the G_Y and G_P amplifiers?

ak. When does relay K24 (81A13) energize?

al. What is the purpose of the $-S_V$ voltage?

am. When time to intercept is clocking down at the correct rate, what is the magnitude and polarity of $\dot{t}$ (S_V equals zero)?

an. What causes the time-to-intercept servo to clock down at a second-per-second rate?

ao. Will the time to intercept increase or decrease if the quantity S_V is positive?

ap. Draw a time diagram for warhead missiles and show the various time delays that occur from burst order to full burst.

aq. What is the potential at terminal 239 in the amplifier cabinet (83C2) when time to intercept is 0.15 second?

ar. When the shaft of the time-to-intercept servo is turning at a second-per-second rate, what is the average output of the t-amplifier?

as. What is the output of the C-amplifier if the potentials at terminals 3 and 2 are 0.25 volt and -0.25 volt respectively?

at. What is the scale factor of the t-input to the C-amplifier?

3. Study questions for chapter 3.

a. State two reasons why limiters are used in the Nike I computer.

b. What is expected to occur in the AZS circuits if an overload condition persists for a considerable length of time?

c. Name the DC amplifiers in the computer which operate with diode limiters.

d. See p 86, TM 9-5000-26. The filament voltages are measured on tubes V1, V2, and V3 and are found to be low. Is this an indication of trouble? Why?

e. Why is it necessary to reduce the maximum order which can be applied to the fins if the missile is above 30,000 feet above sea level?

f. What is the maximum possible output of the G_Y amplifier when the output of the +OL amplifier is 100 volts?

g. Where should the dial of the OL THRESHOLD pot in the left computer amplifier cabinet be set if the MTR is 2,500 feet above sea level?

h. What is the output of the +OL amplifier when the input to the amplifier is zero?

i. Describe how the order-limiting circuits in the fin order solver operate for an increasing velocity error.

4. Study questions for chapter 4.

a. During normal operation, when is the 7g dive order applied?

b. During the period of the 7g dive order, assume that no initial turn order is applied. If t = 40 seconds, what is the input voltage to the G_Y amplifier, and what is the gain of the G_Y amplifier?

c. What point in space is the missile traveling toward in the climb direction when ON TRAJECTORY is received?

d. Why is the input voltage to the G_Y and G_P amplifiers, which develops a 7g dive order, a function of time?

INDEX

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